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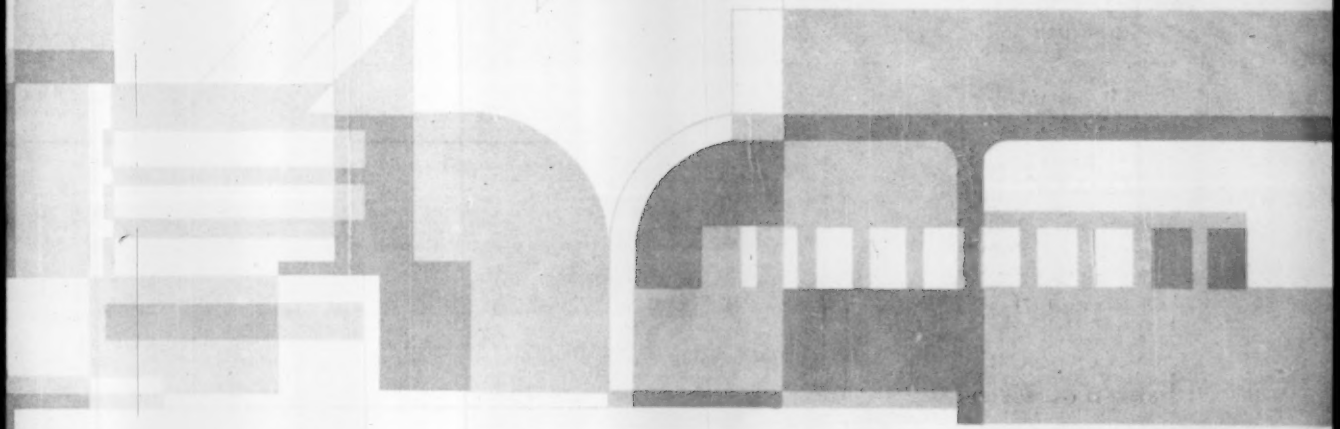

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The Challenge of Operations Research

by **R. N. LEHRER**

Professor and Chairman, Department of Industrial Engineering, The Technological Institute, Northwestern University

SEVERAL years ago, while I still had the time to write editorial features in addition to performing my editorial function for the *Journal of Industrial Engineering*, I prepared a charge entitled "Industrial Engineering at the Crossroads." In this presentation I was rather rough on my fellow Industrial Engineers, for we were truly at the crossroads, and our fate as a fully professional endeavor was in doubt. I am most happy to state that it is my firm conviction that since that time we have passed the crossroads, and have gone a long way on the second mile of professional development.

However, I do feel that our progress should not be taken lightly. We still have much room for further development. We can profit further from the developments originating in fields associated with Industrial Engineering, and from fields far removed from what are commonly thought to be our own.

One of the very significant developments that, at the time of my previously mentioned editorial, was bitterly resented, and resisted by many practicing Industrial Engineers, was Operations Research. The reactions to this area of activity were characterized by either complete rejection or by smug claims that this was nothing new—but was what Industrial Engineers had always done, right from the time of Frederick Taylor. Neither of these reactions was healthy, and fortunately they have evolved into a wholesome attitude—one that allows the progressive Industrial Engineer to take full advantage of the developments associated with Operations Research and to combine these with the best of his own skills and abilities.

The progressive Industrial Engineer is still alert to new developments, and it is along these lines that I shall make my comments. Some confusion still exists concerning the role of Operations Research when compared with Industrial Engineering, and vice versa. Even though a large number of Industrial Engineers have fully embraced the concepts, tools and techniques associated with the Operations Research "scientist," and many educational institutions include Operations Research as a basic element in their Industrial Engineering programs, confusion exists. For example, consider the following statement from a recent publication:

> . . . Many Industrial Engineers have not fulfilled the analytic requirements of modern enterprises. It is unfortunate, though true, that they have lacked the scope of knowledge and experience, sufficient understanding of people, and the mathematical ability which an operations research team can bring into focus on a problem.

This, my fellow Industrial Engineers, is the challenge of Operations Research and Industrial Engineering. Although the typical Industrial Engineer has rather serious limitations relative to an Operations Research "scientist," he also possesses many unique skills and traits that the Operations Researcher ("scientist") does not have.

Perhaps it would help if we were to compare the "modus operandi" of Operations Research and Industrial Engineering. It will reveal that Industrial Engineering can be, and is, an extremely powerful and dynamic profession when properly practiced, and that Industrial Engineering will not be replaced by Operations Research. Quite to the contrary—Industrial Engineering is being magnificently stimulated and nurtured by the developments of Operations Research.

OPERATIONS RESEARCH

Operations Research can be defined in many ways, depending upon the authoritative source one uses for his reference. At best, one might say that the Operations Researcher is one who "researches" operational problems. At worst, one might say that Operations Research is an avenue for non-engineering individuals to become involved with engineering types of problems.

The operations research approach to problem solution frequently involves:

1. A team approach
2. Analytic methods
3. Models and abstractions
4. Mathematics and statistics
5. Probabilistic thinking
6. Complex problems
7. Top management contact
8. A "systems" approach

A TEAM APPROACH

A team approach to involved problems is quite common practice in many industrial organizations. Several individuals, possessing specialized knowledge and skills, should be able to exert more "leverage" on solving problems than one individual, if the problems are complex. However, caution is in order to insure that a "team" approach is not used as a cover-up for inadequate personal and individual abilities and performances. Many of our knotty problems do require much more knowl-

edge and skill for solution than any one individual can reasonably possess. Whether the problem should be approached by a team, or on a consultive basis, should be determined in light of other factors. The Industrial Engineer should be well aware of the importance of "participation" as it aids in gathering accurate and adequate information, generating "ideas," and gaining acceptance for changes. We have learned of the dangers of "expert-ing" changes.

ANALYTIC METHODS

The analytic methods used by the typical Industrial Engineer are quite unsophisticated when compared with those used by the Operations Researcher. However, many Industrial Engineers have used, and are continuing to use, very powerful analytic tools.

The question of analytic methods centers around what is appropriate for adequately solving the problem at hand. Both the Operations Researcher and the Industrial Engineer must have a broad "kit of tools" from which they can select the ones most appropriate for the individual situation at any moment.

Pre-occupation with tools, rather than with the fundamental characteristics of our problems, has been a serious handicap for the Industrial Engineer. When an individual is "tool oriented," he will naturally attempt to use his particular tools for all problems—just like a two year old boy when he gets his hands on a screw driver.

Reliance upon time study, predetermined motion time systems and work measurement, although they have accomplished much in many places, have been the curse of the Industrial Engineer. This area of endeavor has been so fascinating for many individuals that they have become engrossed in it to the extent that they can see nothing else. It is encouraging to note that a large number of Industrial Engineers have developed a balanced perspective concerning work measurement, and now view it as only a means of quantifying the performance of the "work system." This change in point of view has released them for dealing with the other important problems of systems design.

MODELS AND ABSTRACTIONS

Most Operations Research work makes use of "models" and simplified abstractions of the problem. The reliance upon model building is a natural consequence of the scientific training of the Operations Research "scientist." His basic training has been aimed at analysis of problems in order to understand what is happening. The analysis of problems is facilitated if the important or significant factors are singled out and realistically related in a systematic manner. The Industrial Engineer has done this, but most of the models commonly used have been descriptive in nature. The power of model building does not come to light until one considers the quantitative analytic model. Familiar examples would include the O.C. curve for an acceptance sampling plan, the use of a waiting line or queueing model to explain variations in waiting time for a multiple machine tending assignment, and the use of a linear programming matrix to explain the relationships involved in order filling from regional warehouses, etc.

The Industrial Engineer has been, and always will be, pre-occupied with obtaining an adequate and acceptable solution for a problem. This orientation has caused some difficulty, for it has encouraged the use of intuition and discouraged the development of abstract analysis. Operations Research has indicated quite forcefully that many problems have not even been recognized This represents a tremendous challenge to the alert Industrial Engineer.

MATHEMATICS AND STATISTICS

The use of mathematics and statistics is almost essential in any field of engineering. Engineering is the application of science to achieve maximum utilization of the resources of nature, and of human nature, for the benefit of mankind. This use of science requires dealing with quantitative relationships, which in turn requires the use of mathematics. Only when relationships are expressed in a quantitative manner is it possible to manipulate the variables in order to determine what combinations yield an optimum result. (Please note the use of the word "optimum." It implies that we are not seeking just an acceptable answer, but the best or optimum answer to a problem. This is closely related to our previous remarks.)

Operations Research work has been heavily influenced by mathematicians. This has caused some reluctance on the part of the Industrial Engineer in his quest for understanding how this work has been done. It also points up the need for more mathematical versatility on the part of engineers, and a tremendous need for better communication between the mathematicians and all technical personnel. The engineer has no need to become a professional mathematician, but he does need to be fluent in the language of modern mathematics.

PROBABILISTIC THINKING

Nothing is certain in this life but death and taxation, but even these are subject to the laws of probability. Almost all Industrial Engineering problems are probabilistic in nature. The relationships involved are not deterministic, but are of a stochastic character. This fact has been overlooked by many Industrial Engineers in the past, even in view of some excellent work in the statistical quality control field. Perhaps one explanation for the lack of transfer of knowledge from the quality control area to other and more general areas of Industrial Engineering is the preoccupation with rule-of-thumb problem solutions. This preoccupation has tended to block the use of analytical methods of a mathematical and statistical nature. The excellent results achieved by work sampling,

analysis of operational data by statistical means, regression analysis, and queueing theory, to mention only a few probability "tools," have enlightened and encouraged many progressive Industrial Engineers.

Almost as significant has been the recognition by other engineers that their problems also are of a stochastic nature, and that statistical tools are essential for all engineering work. The activities in Operations Research have rendered the entire field of engineering an outstanding service in highlighting the need for statistical skills.

COMPLEX PROBLEMS

Operations Research possesses the aura of mystery in the eyes of many management people. They have been told of the wonders to be gained by a honeymoon with the scientist, but too few understand how Operations Research works. They know that it can be expensive, and that it has been used to solve some very complex problems. This view of the field tends to reserve the Operations Research people for complex problems which have not been satisfactorily solved in the past. Even so, from direct observation and from observations of others, I must conclude that a considerable amount of current "Operations Research" work is scarcely more advanced than sophomore Industrial Engineering.

The growing complexity of most modern businesses also results in the development of many new and complex problems. Frequently, Operations Research is assigned problems that have been considered insolvable. This is the area where "research" in solving operational problems is desired. If the problems were easily solvable, there would be little need for "researching" them.

It would be only fair to point out that "researching" new and complex problems is not within the exclusive province of any group of individuals. But, the approach to these problems is facilitated by the clear analytical thinking usually associated with research training. This training should be common to all engineers, including the Industrial Engineer.

TOP MANAGEMENT CONTACT

The complex problems usually associated with Operations Research, the importance of these problems, and frequently the expensive nature of a formal Operations Research undertaking, all lead to close contact with top management. This is fortunate, for top management contact is essential when dealing with problems that require company-wide analysis for proper solution. This contact also lends the activity an air of respectability that is most helpful.

Operations Research has been described as the "science of decision." This name implies that problems are solved by analysis of various alternative courses of action, in terms of the requirements and consequences, so that top management can base their decisions on adequate factual information in addition to their quantitative and intuitive evaluations. This interpretation lacks the "practical" flavor of engineering, for it begs the problems of practical installation of a plan of action. This is an area where the engineer shines. Not only must alternative courses of action be determined and evaluated, but they must be made to work.

A "SYSTEMS" APPROACH

The most significant aspect of Operations Research, and one that has been enthusiastically adopted by the Industrial Engineer, is the "systems" approach. Problems must be solved in terms of their effect upon the entire organization. This philosophy is neatly expressed by "optimize" rather than "sub-optimize." The systems approach leads to consideration of what areas within an organization are most likely to yield improvement in the "over-all" operation of the concern. Most of the traditional Industrial Engineering activities are, by their very nature, restricted to small parts of an organization's "system," and can only result in sub-optimization. A new and broader view of the over-all problems of a company is yielding substantial results. Sub-optimizing can improve the operation of an organization's system, but only within the limits characteristic of the system. Further improvement can be achieved only by improving the basic design of the system and its sub-systems.

MODERN INDUSTRIAL ENGINEERING

Most of you are familiar with the AIIE definition of Industrial Engineering that appears on the back cover of the *Journal of Industrial Engineering:*

> Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

I would like to highlight a few of the important words in this definition, for they have considerable pertinence to the present subject. *Design; Integrated Systems; Specialized Knowledge and Skill in the Mathematical, Physical and Social Sciences; Engineering Analysis and Design.*

Design is one of our most important functions. The Industrial Engineer is primarily concerned with designing situations or systems which achieve desired objectives in an economical (or optimum) manner. The implication of design is that the schemes that are devised are developed in a logical and orderly manner, based upon knowledge of factors involved in the problem and how they behave relative to the desired result. Design also implies that problems are anticipated and solved before they occur.

Integrated Systems are the core of Industrial Engineering. We are concerned with the broad implications of solving specific (and often seemingly restricted) problems. The impact of changes must be related to the over-all company operation—we must deal with the "system," and work toward optimization rather than sub-optimization.

Specialized Knowledge and Skill in the Mathematical, Physical

and Social Sciences. All engineering is based upon the use of science in solving practical problems. Industrial Engineering differs from other areas of engineering endeavor primarily in that additional factors relating to human behavior are involved in most of our problems. We must use the fund of knowledge developed in the social sciences, as well as knowledge from mathematics and the physical sciences, if we are to solve problems of integrated systems of men, materials and equipment.

Engineering Analysis and Design again emphasize the fundamental engineering nature of our work. We perform an engineering function, but one which is unique. We are essentially engineers *for* management in that we apply engineering knowledge to the analysis and design of production or work systems, to control systems which allow these work systems to perform effectively, and to the development and evaluation of alternative courses of action for which management needs factual information.

UNIFICATION

The objectives of Operations Research and Industrial Engineering have much in common. The point of view is perhaps somewhat different, as it should be. However, both the Industrial Engineer and the Operations Research scientist can benefit greatly from cross-fertilization and close association. The Operations Research scientist should remain a scientist in his orientation. The Industrial Engineer should remain an engineer—and be preoccupied with solving practical problems. This is the extent of desirable differentiation.

Obtaining the unification of Industrial Engineering and Operations Research, which I feel is so necessary, will not be easy. But, I do believe it will be a reality in the near future. Educational programs in the outstanding universities throughout America give substantial encouragement along these lines. Our new Industrial Engineering program at the Technological Institute of Northwestern University is an example of the "new look" in Industrial Engineering. The program is built around engineering analysis and design of work systems. Operations Research is an integral part of all the Industrial Engineering courses. The program is receiving very favorable recognition.

OTHER CHALLENGES

Our discussion has been confined to the challenge of Operations Research. Although this is a most important aspect of Industrial Engineering, I feel obliged to mention several other, but not wholly unrelated, developments that can also be regarded as challenges to Industrial Engineering. These are: Automation; Computers (both digital and "analogue"); Data Processing (not confined only to Electronic Data Processing); Behavioral Science; and "Systems" Engineering. All of these topics deserve extensive and careful consideration, for they are of the utmost importance to the Industrial Engineer. They all complement the skills and abilities already well developed, and they open new avenues of problem solution that are most exciting.

MEETING THE CHALLENGE

Assuming that you are sympathetic to my point of view, let me conclude with a few remarks concerning the ways in which we might meet the challenge. Operations Research, and all of the other new developments of importance to Industrial Engineering, do not represent a displacement of Industrial Engineering. They are means of making Industrial Engineering more effective. But the problem of integrating the new developments is a considerable one. New skills and knowledge must be acquired. If we are willing to wait, the new skills will be available in the new graduate Industrial Engineers produced by the progressive universities. This will be a slow development, and will not provide for the continuing developments that are of importance. The alternative course of action is one of self development. This can be facilitated by your association with AIIE, both in chapter and national activities. I would strongly recommend that you investigate chapter sponsored educational programs. The challenge can be met.

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Significant Figures in Measurements

by **MICHAEL V. SMIRNOFF**

Associate Professor of Civil Engineering, North Carolina State College

THIS article discusses the question of the significance of figures employed in recording observed values of measurements and in computations involving such values.

Since the true values of measured quantities must remain forever unknown, it is possible to obtain by measurements only approximations to true values. Such approximations are called *most probable values,* abbreviated sometimes MPV. Thus a length measured to the nearest foot and recorded as 352 feet has this measurement as the most probable value of the length measured. If, however, the same length is measured to the nearest tenth of a foot and recorded as 352.0 feet, then this last measurement would become the most probable value of the length measured, since it is a better measurement than the former, and so on. In each of the above two examples every recorded digit has a meaning and thus is a *significant figure.* There are three significant figures in 352 and four in 352.0. It should be obvious that it would be incorrect to record 352.0 in the first measurement or 352 in the second.

Not all recorded figures in a measurement may be accurate. For instance, a distance recorded as being 438 feet long might have been measured by pacing, in which case one could be quite sure that there are 4 hundreds in the measured distance and also reasonably sure that there are 3 tens. However, the number of units recorded as 8 may be in doubt, perhaps by as much as 7, 8, or more feet. The question arises then whether 8 in 438 is still a significant figure.

It is said that *a figure is a significant figure if its uncertainty is less than ±10 units in its place.* Thus 8 in 438 will cease to be a significant figure when it is in doubt by 10 or more units. Similarly 3 in 438 will not be a significant figure if its uncertainty is 10 or more units in its place, and so on. However, showing 438 as 440 if units are not significant, or as 400 if tens as well as units are not significant, would be misleading, since recorded zeros might be taken as being significant figures. There seems to be no standard way to designate the last significant figure in a recorded measurement. The method that will be followed in this article will show the last significant figure by underscoring. Thus 43̲0 will signify that units are not significant and 40̲0 will signify that tens as well as units are not significant. But a measurement recorded as 400 must be taken as having three significant figures.

It must be also noted that any zero preceding the first non-zero digit is not counted as a significant figure. For instance, a measurement recorded as 0.050 has only two significant figures.

EXACT NUMBERS

Since no measurement may have an exact value, the exact numbers, i.e., mathematically correct numbers, may be found only in non-measured values. Counting, for instance, may be recorded by an exact number, such as counting three sides of a triangle. This 3 may be recorded as 3.000 . . . *ad infinitum.* It has infinite number of significant figures; nevertheless it must be correctly written as 3, since it is not a measured quantity. Many constants in formulas have infinite number of significant figures, like 2 in the area $\frac{ab}{2}$ of a right-angled triangle having sides a and b.

SIGNIFICANT FIGURES IN COMPUTATIONS

It is important to know how to ascertain the number of significant figures in the result of computations involving measured quantities. Often it is possible to determine the number of significant figures in a result by a rule of thumb, but some times it is advisable to make a few simple calculations.

ADDITION

Let it be required to add three measured quantities, 3.75, 7.912, and 4.526. Whether the empty space where thousandths should have been recorded in 3.75 has any significance depends on how close the hundredths were ascertained. For instance, if 3.75 is known only to the nearest ±0.02 units, the true value must be between 3.740 and 3.760. This range makes thousandths not significant because they are uncertain by ±10 units in their place. However, should 3.75 be known to the nearest 0.01 unit, the range of uncertainty will be from 3.745 to 3.755 which makes thousandths uncertain only by ±0.005 or by ±5 units in their place. This makes thousandths significant even though they were not recorded.

The implication of the foregoing discussion is that in adding 3.75, 7.912 and 4.526, the thousandths must be retained and the sum given as 16.188.

Of course the argument for retention of thousandths in the above example would be much weaker if two out of three given numbers did not have thousandths recorded,

like in the set of numbers 3.75, 7.91, and 4.526. However, a careful computer would add these three numbers as 16.186 and then, if it is the last operation to be performed, he would give 16.19 as the final result, thus rounding it off to hundredths.

In rounding off a number, i.e., in discarding the last (or sometimes few last) digits, one must be added to the last retained figure if discarded figures are 5, 6, 7, 8, or 9 (five altogether), and the last retained figure must be left unchanged if discarded figures are 0, 1, 2, 3, or 4 (also five altogether). So-called "computer's rule" in rounding off the numbers should not be applied to measured quantities. The rule is apparently devised for non-measured values where a zero at the end of the number like 5.460 normally would not be recorded, as being superfluous. It is not superfluous in a measured quantity. Zero is a number and, in measuerments, it must be treated like any other digit.

SUBTRACTION

Subtraction is the reverse of addition; thus the same rules that are used for addition must hold true for subtraction.

MULTIPLICATION

The rule for the retention of significant figures in multiplication may be worked out for two measured quantities, a and b, and then extended to any number of factors. Let Δa and Δb be the errors in a and b respectively. Also let ΔP be the resulting error in the product, $P = ab$. All above errors could be either plus or minus, but in the process of derivation of expressions below only positive sign for deltas will be used. The errors thus computed will be maximum errors, since no cancellation of terms will be possible.

Applying respective deltas to a, b and P, the following equation will result:

$$P + \Delta P = (a + \Delta a)\ (b + \Delta b) \qquad \text{Eq. 1.}$$

By multiplying out and discarding a relatively small term, $\Delta a \cdot \Delta b$, Eq. 1. reduces to

$$P + \Delta P = ab + \Delta a \cdot b + \Delta b \cdot a \qquad \text{Eq. 2.}$$

By subtracting $P = ab$ from Eq. 2., and then dividing the result by $P = ab$, a very useful equation is obtained.

$$\frac{\Delta P}{P} = \frac{\Delta a}{a} + \frac{\Delta b}{b} \qquad \text{Eq. 3.}$$

The same type of equation may be derived for any number of factors. For instance, Eq. 4. may be derived for the product $P = abc$.

$$\frac{\Delta P}{P} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c} \qquad \text{Eq. 4.}$$

Every term in Eq. 4. shows the ratio of the error of a quantity to the quantity itself. Such ratios are generally called relative errors, or, if they are applied to the precision of measurements, they are called precision ratios. Thus, in words, Eq. 4. states that *the relative accuracy (error) of a product is equal to the sum of the relative accuracies (errors) of its factors.* The word accuracy means proximity to a true value. Thus the smaller the error, the greater the accuracy.

Of course every term in Eq. 4. may be multiplied by 100 in which case the equation could be stated still in another manner, namely: the percent of error of a product is equal to the sum of the percents of errors of its factors.

By solving Eq. 3. and Eq. 4. for ΔP the number of significant figures in a product can be easily determined.

Example 1. Two sides of a right-angled triangle were measured as $a = 3.72$ feet and $b = 7.54$ feet. The respective accuracies in these measurements were 1:200 and 1:500. It is required to express the area of the triangle to a proper number of significant figures.

Solution: Carrying out complete multiplication,

$P = \frac{ab}{2} = 14.0244$ and from Eq. 3.

$\frac{\Delta P}{14.0} = \frac{1}{200} + \frac{1}{500}$. Solving this for ΔP,

$\Delta P = 0.098$. Rounding this to the nearest 0.01, and introducing plus or minus sign in front of the result,

$\Delta P = \pm 0.10$. This shows that the uncertainty of hundredths is 10 units in their place; thus hundredths in the area are not significant and the area should be given as

$P = 14.0$ sq. ft.

It may be noted in the foregoing example that both lengths a and b were measured to three significant figures, and that the product, P, also came out with three significant figures. This, however will not always be the case, because if a in the above example had been given as, say, 2.92 instead of 3.72, the hundredths in the product would be significant and the area would have four significant figures.

As a rule, *the number of significant figures in a product will be either the same as the number of significant figures in the least significant factor, or greater by one significant figure.* The least significant factor is one which has the smallest number of significant figures.

Since it would be a greater blunder to lose significant figures in computation than to retain those that are not significant, a safe rule in multiplication should be to retain in the product one significant figure over those in the least significant factor. If more accurate results would be required, the proper number of significant figures could be ascertained by using Eq. 3.

Multiplication of any two measured quantities, expressed in the same units, can be represented graphically by the area of a rectangle shown on Figure 1. The shaded portion of the area represents the uncertainty in the product due to errors Δa and Δb in the factors a and b. The cross-hatched corner of the area represents the product $\Delta a \cdot \Delta b$ which was discarded in the derivation of Eq. 3. as being negligible.

DIVISION

The same rules which apply to multiplication will apply to division, since division of two numbers like $\frac{a}{b}$ may always be represented as a product of a and $\frac{1}{b}$, where $\frac{1}{b}$ will have the same number of significant figures as b.

POWERS

Elevation into a power is the same as successive multiplication of a number by itself the number of times equal to the exponent. Thus multiplication rules will also apply in this case.

ROOTS

Consider a general expression, $\sqrt[n]{A} = x$. Elevating both sides of this expression to the n^{th} power, $A = x^n$. Thus

$$\frac{\Delta x}{x} = \frac{1}{n}\,\frac{\Delta A}{A} \qquad \text{Eq. 5.}$$

This shows that the percent of uncertainty in a root will be equal to the percent of uncertainty of the radicand divided by the power of the root. Let it be required, for instance, to find the number of significant figures in $\sqrt[3]{125}$. If it will be assumed that 125 is known within, say ± 1 unit, then $\frac{\Delta A}{A} = \frac{1}{125}$, $n = 3$, and $x = 5$. Substituting these values in Eq. 5. and solving for Δx, $\Delta x = \frac{1}{75} = 0.01$. This means that hundredths in $\sqrt[3]{125}$ are significant, so that the answer must be given as 5.00. Applying this dimension to the side of a cube, it means that in order to have the volume of the cube to the nearest cubic foot, 5-foot sides must be measured to the nearest 0.01 of a foot.

As a rule, the number of significant figures in a root will be either equal to those in the radicand or greater by one significant figure. For instance, $\sqrt{3}$ must be given as 1.7 if 3 is known to the nearest unit. When in doubt, the question may be easily resolved by application of Eq. 5.

Example 2. A time study of an operation, subdivided into three elements, has been taken with the results shown in Table 1 for ten cycles. The number of cycles for illustration in this example has been selected quite arbitrarily. Recordings were in minutes by reading a stop watch graduated to hundredths of a minute. Thus readings are to the nearest hundredth of a minute, or within ± 0.005 minute.

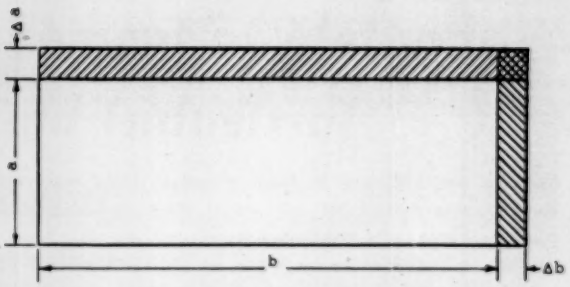

FIG. 1

The rating factors, by which the average time per element must be multiplied, are as follows:

Element	Rating Factor
1	115%
2	125%
3	110%

The rating factors are based on the estimates of the operator's speed within about $\pm 5\%$.

The average time per element multiplied by the rating factor gives the normal time per element.

TABLE 1

Element	Cycle									
	1	2	3	4	5	6	7	8	9	10
1	0.07	0.44	0.79	1.16	1.51	1.88	2.23	2.58	2.93	3.31
2	0.21	0.57	0.93	1.32	1.65	2.01	2.36	2.72	3.07	3.46
3	0.36	0.73	1.08	1.45	1.81	2.15	2.51	2.87	3.23	3.60

Summation of normal time for all elements divided by $1 - 0.14$ gives the standard time of operation. The number 0.14 is the allowance for interruptions and other unplanned-for events. It is estimated in percent, i.e., 14%, to the nearest 1% or within $\pm 0.5\%$. (Some computers prefer to add $100(\frac{1}{0.86} - 1)$ equals 16% to the normal time, in order to obtain standard time, which should give the same result.)

It is required to determine the number of significant figures for the standard time of operation in this example.

Solution: In order to determine the average time per element it is necessary to find the differences between two successive stop watch readings and take the average of ten cycles per element. The results are arranged in Table 2.

In order to ascertain the number of significant figures in the average times shown in Table 2, it is necessary to

TABLE 2

Element	Time in Minutes for Each Cycle										Average Time
	1	2	3	4	5	6	7	8	9	10	
1	0.07	0.08	0.06	0.08	0.06	0.07	0.08	0.07	0.06	0.08	0.071
2	0.14	0.13	0.14	0.16	0.14	0.13	0.13	0.14	0.14	0.15	0.140
3	0.15	0.16	0.15	0.13	0.16	0.14	0.15	0.15	0.16	0.14	0.149

find the uncertainties in these average times, knowing that the readings of the stop watch were within ± 0.005 minutes. Since these readings were subject to random variations, it is necessary to apply to the uncertainties in reading the stop watch the same rules which are applied to probable errors. One rule is that the error will vary according to the square root of the number of opportunities to present itself.

Since there are two chances for error in each time period for a cycle, the uncertainty in the recorded time in minutes for each cycle will be $\pm 0.005\sqrt{2}$. Similarly, the uncertainty in the average time per element will be

$\pm\dfrac{0.005\sqrt{2}}{\sqrt{10}}$ equals ± 0.0022, since the average time of 10 cycles is taken in this example. The result shows that the thousandths in the average time are significant.

In order to find the amount of uncertainty in the product obtained by multiplying the average time per element by the rating, Eq. 3, may be used and the necessary computations may be conveniently arranged in a tabular form as is shown in Table 3.

TABLE 3

Element	a	Δa	$\dfrac{\Delta a}{a}$	b	Δb	$\dfrac{\Delta b}{b}$	P	$\dfrac{\Delta P}{P}$	ΔP
1	0.071	0.0022	0.031	1.15	0.05	0.043	0.082	0.074	± 0.0061
2	0.140	0.0022	0.016	1.25	0.05	0.040	0.175	0.056	± 0.0098
3	0.149	0.0022	0.015	1.10	0.05	0.045	0.164	0.060	± 0.0098

Table 3 shows that the thousandths in the product $P = ab$ are significant, even though by a very small margin for the second and third elements. Thus in adding total normal time for three elements the sum should be given as $0.082 + 0.175 + 0.164 = 0.421$.

In order to get the required standard time of operation, the total normal time must be divided by $1 - 0.14 = 0.86$ which is uncertain by ± 0.005 units. The range of uncertainty is then between 0.855 and 0.865; or the range of uncertainty of $\dfrac{1}{0.86}$ will be between 1.170 and 1.156 or ± 0.007.

In this case the product $P = 0.421\ \dfrac{1}{0.86} = 0.490$. Let it be assumed that $a = 0.421$ and $b = \dfrac{1}{0.86} = 1.16$; Δa may be taken as the average of uncertainties shown in the last column of Table 3 multiplied by $\sqrt{3}$. The average value of the last column in Table 3 is ± 0.0086, thus $\Delta a = 0.0086\sqrt{3} = 0.015$. It may be noted that very closely the same result would be obtained by adding the last column of Table 3 as the probable errors of three quantities. This last method may be preferred when the uncertainties vary considerably. Also $\Delta b = 0.007$ as computed.

$$\text{Thus } \frac{\Delta P}{0.490} = \frac{0.015}{0.421} + \frac{0.007}{1.16}, \text{ or } \Delta P = \pm 0.020.$$

This shows that the thousandths in the standard time of operation (0.490) are not significant and the answer should be given as 0.49.

VACANCY UNIVERSITY OF FLORIDA

The College of Engineering, University of Florida at Gainesville, Florida, is currently considering applications for the position of Head Professor of Industrial Engineering. The present department head has requested that he be permitted to return to full time teaching and research. Applications should be addressed to Joseph Weil, Dean. Suggestions from non-applicants as to qualified personnel would also be appreciated.

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The Economic Management of Methods Development and Industrial Engineering

by **JAMES W. THOMPSON**

Division Industrial Engineer, Argus Cameras, A Division of Sylvania Electric Products Company, Ann Arbor, Michigan

THE VALUE of continuing methods improvement is recognized in progressive companies. Such organizations have ambitious programs planned for the installation of better methods. Budgets reflect the decision to install better tools and equipment. Sound managers realize, however, that it takes more than expenditures to achieve results. Automatic equipment, trick fixtures, and new tools usually offer a return for the investment; but often do not.

An economic analysis of the costs of improvement versus the expected return is stressed in periods of tight financing. Periods of more liberal financing usually come at a time when engineers are already overworked by an expansion program. Thus we find expenditures made without careful consideration under the excuse that engineers are "too busy." The Unit Labor Index offers a simple yet effective evaluation technique that can be used by the busiest engineer.

ENGINEER SHORTAGE

Much has been said and written about the shortage of engineering skills. We are told that this shortage will continue. One of the solutions offered is better use of the engineer's time through good engineering management planning, use of technicians, specialization, and the like. The solution is in recognition of the fact that a part of the shortage is due to poor use of the engineer's time. The technique described in this article was developed at Argus Cameras, to direct the application of Industrial Engineering effort to those areas likely to give greater financial return.

The experience reported in this article is particularly applicable in the field known as "methods engineering." The field is considered in its broadest sense. It includes all of those many skills contributing to sound methods. In addition to the Industrial Engineer, the field includes the Project Engineer, Production Engineer, Tool Engineer, Tool Designer, Tool Maker, Set-up Man, Production Supervisor, and others.

A PRODUCT IMPROVEMENT PROGRAM

Several years ago Argus Cameras conducted a product improvement program. The project followed the usual pattern. A committee of production and engineering personnel met at regular intervals. A part of the product was selected. Questions were asked, such as "What have been our problems with this part?" and "What can we think of that will solve the problems?" Suggested improvements were assigned for action and reviewed at subsequent meetings.

In evaluating the results of the program, it was found that the over-all savings were substantial for the product involved. Many of the nuisance problems were solved. All of the people working on the committee became more closely associated as a result of discussing each other's problems. On the other hand, some of the tools ordered were not justified by the savings realized. Many of the areas of greater potential savings were overlooked because no immediate problem was suggested. Areas of lesser potential were attacked with enthusiasm as one or more committee members advanced an inspirational type of idea. The product selected for review was finally found to have a far lesser potential savings than others being manufactured. It was apparent that some guide was required for future endeavors.

Accordingly, economic formulas and analysis techniques were reviewed. The "in favor of" type of analysis and accounting formulas of savings versus costs, life, and other factors were considered. The popular text "Methods-Time Measurement" deals with the annual cost per ten "TMU's" (1). Another book "Operation Analysis" describes classes of methods studies (2). These and other sources formed the basis for the development of a rational guide for the profitable use of engineering time in methods improvement activities.

INDUSTRIAL ENGINEER'S TIME GUIDE

The guide was developed at first for the self guidance and direction of Industrial Engineers. Our company operates an incentive plan of wage payment, and, as a result of product expansion and engineering changes, there is always a constant pressure for time standards on new or changed jobs. As a result of the shortage in engineering talent, seldom was it possible to adequately establish the methods before a time study was taken.

Trained Industrial Engineers were in short supply, as in most other plants. As a result of insufficient coverage, pressure was for a standard of any sort and seldom was a complaint placed because of an incomplete methods analysis. A review of the standards pressure showed that it was the result of a large number of low activity operations representing a small portion of the direct labor cost. The same methods analysis and measurement techniques were being used in all problems. Highly repetitive operations offering a high return on methods improvements were sometimes receiving less attention than operations measured only to continue incentive coverage. Industrial Engineers appeared at a loss in the selection of the degree of analysis to use.

UNIT LABOR INDEX

The Unit Labor Index was developed as a guidance technique. The index was used to specify the action techniques of Industrial Engineering that were economically justified. The Industrial Engineering Supervisors could thus be assured that engineers were using techniques *likely to give the greatest return for their efforts.*

As its name indicates, the index refers to labor cost. It is selective in that it emphasizes labor cost and its potential. It is an index of the cost of repetitive labor. A useful index could be based on this factor alone, repetition. For the continuous comparison of alternate methods, we have found it more advantageous to use a money index.

The Index was calculated by the following general formula:

$$\text{Unit Labor Index} = \frac{\text{Hourly Rate}}{60} \times .01 \times \text{Expected Repetitive Life}$$

The hourly rate divided by 60 minutes, or minute rate, was an average for all production employees. It was found that variations in hourly rates had little affect on the *decisions* made by the use of the index. The minute labor rate was, further, consistent with the standard cost system in use.

The factor, .01, reduced the calculation to the basic measuring system (hundredths of a minute) of the Industrial Engineering group. Experiments were conducted on an index based on the second in time measurement. The factor was found to be used to the decimal minute and it was more acceptable than seconds.

The "Expected Repetitive Life" was a forecast of the number of that model yet to build; with one exception. A survey showed that while a model may have public acceptance for many years, its parts were in constant revision. Experience showed that a part had an average life of three years before a major revision took place. Accordingly, the expected repetitive life was limited to the units forecast for the next three years.

The Unit Labor Index has been in use at Argus for several years, and everyone—foremen, process engineers, tool designers, as well as Industrial Engineers—refers to it as the "ULI." About thirty minutes a month are required to maintain product ULI figures.

The ULI varies, by product, from less than ten cents to nearly three hundred dollars. It is apparent from this wide spread that scarce engineering talent should be concentrated in those jobs with high potential savings.

USES OF ULI

The practical use of the ULI was markedly demonstrated in the layout and tooling of a product assembly line. A committee of personnel from project engineering, quality control, supervision, and Industrial Engineering was formed to develop this project. At the first meeting, an explanation of the meaning and dollar value of the ULI was given. Many ideas for improvement were thus ruled out without loss of investigation time when it was apparent that the effort was not justified. Other methods advanced as "the way we do this" were restudied with greater emphasis when it was commonly understood that savings were possible for even a small amount of time saved. Substantial savings were obtained by the committee.

The ULI is similarly used to guide equipment selection, as illustrated by the conversation between an equipment salesman and a project engineer. The salesman was extolling the savings in time afforded by a double unit instead of a single unit. The project engineer was familiar with the ULI for the product. He did some rapid, mental calculating and replied that it would take about ten years of savings to justify the increased expenditure. The single unit was selected as it should have been. It has been our experience that people working continually with a product will remember and use the ULI figures.

One department foreman took part in developing the concept of the index. He recognized its value in concentrating the efforts of the set-up men and supervisors in the areas of greatest return. Accordingly, he has stressed the index figures in department meetings. He reports improved set-ups, operation improvements, elimination of unnecessary operations, reduction of costly delays, and better job instruction as a result of the awareness of the value of a small unit of time, even on familiar, previously accepted, operations.

The factors used in the index formula are easily explained as a common sense approach. The concept is thus quickly grasped by production employees. The philosophy has been used in the "value of a second" campaigns and suggestion plan publicity.

ULI AND INDUSTRIAL ENGINEERING ACTIVITIES

Although the ULI has been used as a guide in many activities, its major service has been in the guidance of Industrial Engineering activities.

The Industrial Engineering Department works under the concept that methods and time standard activities

are inseparable. A Job Study, therefore, includes application of techniques of three phases—methods study, standard setting, and operator instruction. There are varying degrees of each of these phases. Methods study for example may be the application of current operating practices, or it may mean the use of work simplification analysis, or a more exact motion study. Similarly, there is progressive accuracy in various techniques of work measurement, and operator training of all sorts. There are techniques in each of these phases that naturally go together. It is possible to develop an assembly station in a methods laboratory, then release it to production without any form of instruction, and measure the work with simple over-all watch readings. This is not likely, however, for a job that will justify methods laboratory techniques would similarly justify motion by motion training for the operator, and careful measurement by motion-time techniques checked by timed performance and delay analysis.

Standard practices have been developed to include many of the acceptable techniques in all three phases of job study. We do not believe, for example, that we should be known as a stop watch time study plant or a predetermined motion-time plant, but rather that all techniques have their proper place in the scheme of our activities. Recognizing further that there is a natural grouping of techniques in all three phases of job study, we have grouped commonly available techniques into types of job studies.

TYPES OF METHODS AND STANDARDS STUDIES
INDIVIDUAL OPERATIONS

Type A for ULI over $300
- Written operation analysis
- Motion picture analysis
- Methods-time measurement analysis in methods laboratory
- Detailed motion training of operators
- Record of operation by methods-time measurement
- Detailed operation description card

Type B for ULI between $75 and $300
- Written operation analysis
- Methods-time measurement analysis
- Written operator instructions
- Record of operation by methods-time measurement
- Detailed operation description card

Type C for ULI between $15 and $75
- Mental operation analysis
- Record and standard by methods-time measurement or time formula work sheet
- Verbal operator instruction
- Elemental operation description card

Type D for ULI between $3 and $15
- Standard by time study or time formula application to good operating practices
- Elemental operation description card

Type E for ULI under $3
- Elemental data application, comparison with similar operations, or working-idle analysis

The more detailed the study, the greater the amount of time required to make it. In any specific problem study, the savings affected must at least equal the cost of making the study if the expenditure is to be justified from an economic standpoint.

ECONOMIC PROCEDURE

Unless management is willing to accept a single package of techniques applied to all operation studies, it must decide on the degree of study for each problem presented. The use of the ULI has almost eliminated this constant decision by incorporating the economic concept into a standard procedure. Factors that normally indicate the amount of study as discussed above were considered in establishing a range of ULI values under which a specific group of methods and standards techniques would be used. The range of values currently in use are given in the outline of the "Types of Methods and Standards Studies."

A ULI of $62 for an operation indicates that the Industrial Engineer is to use the group of techniques specified for a type C study. He makes a mental operation analysis on the operation, that is, he applies the questioning attitude to the operation as observed, looking for common improvement possibilities. He installs those improvements after he has justified them by a comparison of the estimated cost of the improvement and the estimated savings indicated by the ULI. Since the ULI in this example indicates the justification of a good record of the method affecting the time standard, he records the method in terms of the Methods-Time Measurement notation. At this level of potential savings, however, he will not labor over difficult changes that offer minor motion pattern improvements, even though the measuring technique often suggests them. Operator training on the operation is merely instruction in good operation practices, the proper tool layout, and the proper sequence of operation elements. The engineer, therefore, causes a description to be prepared that is merely a listing of the operation elements in sequence of performance. He attaches a photograph of the set up observed.

A different value of the ULI for an operation may indicate a different type of study employing a different group of techniques. This does not, however, have any specific effect on the amount of time the engineer is to spend on the operation. A new operation obviously will require more engineering time than one similar to many others well established. Similarly, long, complex operations require more time than short, simple ones. The specific technique, however, is one that is likely to permit optimum justifiable savings from the engineering time required regardless of the state of methods development or the length of the operation being observed.

To avoid the necessity of calculating the ULI for each operation approached, product ULI's are published each month. Engineers working with a product usually have

no difficulty in remembering the dollar values. A product ULI assumes that the operation occurs once for each finished assembly, and that the operation will be required for the expected life of the product. The Engineer approaching the operation study need only to check these two assumptions and mentally factor the known ULI.

This explanation of the use of ULI as a guide to Industrial Engineering studies is simplified by considering only individual operation studies. The engineer must on occasions approach a new type of process applied to many similar operations. He will analyze them as a group and thus employ slightly different techniques. He uses a time formula, for example, to establish standards rather than make an individual methods-time measurement analysis. The calculation of the ULI is more complex since several parts of several products may be involved. The philosophy of the ULI approach is being used at Argus for groups of operation studies, although it has not reached the same degree of standardization as has the individual operation approach.

RESULTS FROM ULI

It has been our experience that the output of the Industrial Engineer is increased by the application of this procedure. This is probably due to two reasons; first, the Engineer is more certain of the techniques expected of him; and secondly, he avoids lost time of making detailed methods studies in low activity areas. On the other hand, the quality of methods work on higher activity work has been steadily improving.

REFERENCES

(1) MAYNARD, STEGEMERTEN AND SCHWAB, *Methods-Time Measurement*, McGraw-Hill Book Company, 1948.

(2) MAYNARD AND STEGEMERTEN, *Operation Analysis*, McGraw-Hill Book Company, 1939.

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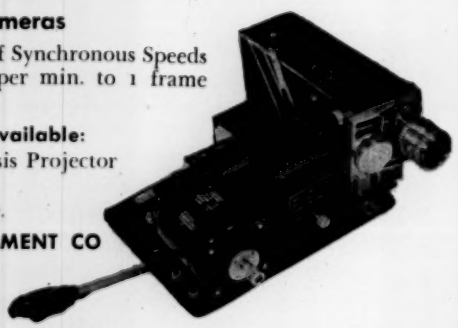

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Measuring Physical Effort

by **INGO INGENOHL**

Assistant Professor of Industrial Management, Massachusetts Institute of Technology

HUMAN work is intimately associated with measurement. Whatever and whenever we produce, we are also always measuring. Wherever human beings work they are interested in answers to these questions:

> How much did we do?
> How well did we do?

If we work and produce for organizational objectives rather than personal ones, an additional question arises:

> What is required on the job?

There are at least two aspects of work or "effort": 1. a subjective psychological interpretation of a physical and mental experience and 2. an objective engineering interpretation of energy expenditure. Here we shall be concerned only with the latter: Industrial Engineering methods of evaluating physical energy expenditure in the course of industrial work performance.

Our review of this Industrial Engineering methodology shall consider the following four factors:

1. Conditions and objectives which led the Industrial Engineer to recognize the compelling need for discriminating evaluation and/or measurement of energy expenditure.
2. The techniques of such measurements and evaluations.
3. Internal consistency and inter-reliability of various formulae, adapted from physics and mechanics, used to express human energy expenditure.
4. Validity of these "mechanical work" formulae in terms of composite ratings of physical effort.

Finally, a new and somewhat different modification of the "mechanical work" formula is presented. It does not claim to be "measurement" in any sense of the scientific term, but is offered rather as a rule-of-thumb evaluation of energy expenditure. It is suggested primarily as an *aid to other methods of rating physical effort,* such as rating by verbal definitions. Thus, the validity of this rule-of-thumb formula is expressed in terms of a composite rating criterion; pointing however toward a number of areas for fruitful research which eventually may enhance the usefulness of such a semi-mechanical "effort" formula.

CONDITIONS AND OBJECTIVES

The conditions that led Frederick Winslow Taylor to his concept of scientific management were described quite comprehensively by Viteles (25) in just one sentence:

> Management had no idea of man's working capacity and had completely failed to provide instructions in methods of work that would permit the worker to use his capacity to best advantage.

Taylor's objectives and those of the modern Industrial Engineer are essentially the same: 1. knowledge about man's capacity for work, 2. adequate and, hopefully, fair remuneration for effort rendered toward production goals and 3. minimization of economic costs through minimization of production time. Measurement of energy expenditure was done with the objective of reducing it. Conditions to attain this objective were favorable: a healthy growing economy, a management philosophy that men should never do what a machine can do and an unlimited faith in our engineering ability to design work processes at will.

While the objectives may still be the same, conditions have changed somewhat. The time study man observing a job which in part requires a great physical strength and effort still recognizes the necessity of incorporating some measurement of difficulty into the standard time for these job elements. He even has a theoretical framework for the relationship between time, pace and performance (17) as well as knowledge about the possible range of human capacities (5). Yet, more often than not this measurement *just is not done!* It is cumbersome and difficult and the problem is frequently disposed of by adding an overall fatigue allowance to the total measured time. When rating operator performance, for example, with the leveling system (13) the time study man knows that his judgment of what constitutes a 100% or "average" performance should be influenced by the demands on physical strength and exertion.

The job evaluation analyst is probably the one who most keenly needs to pay attention to job conditions that require physical strength and effort. Their correct description and evaluation relative to the over-all "value" of a job is part of his scheme and it is his duty to compare each job with some predetermined definitions from his manual. Not only must he determine a correct point value for the physical job requirements according to the available point range of his system but he must also rank this energy expenditure in proper relations to other jobs in the plant. Mostly he has only words with which to do it.

Figure 1 shows such a rating scale for physical effort. The table is typical for the kind of job evaluation systems which use verbal definitions only (14).

This being unsatisfactory, some job evaluation systems attempted to add "real measurements" to their verbal definitions. It could not be measurement of the actual

Item 4: Physical Demand	Point Range
This factor appraises the amount and continuity of physical effort required. Consider the effort expended handling material (the weight and frequency of handling), operating a machine or handling tools, and the periods of unoccupied time.	
40. Light work requiring little physical effort	0–10
41. Light physical effort working regularly with light weight material or occasionally with average weight material. Operate machine tools where machine time exceeds the handling time.	11–20
42. Sustained physical effort, requiring continuity of effort working with light or average weight material. Usually short cycle work requiring continuous activity, the operation of several machines where the handling time is equivalent to the total machine time.	21–30
43. Considerable physical effort working with average or heavy weight material, or continuous strain of difficult work position.	31–40
44. Continuous physical exertion working with heavy weight material. Hard work with constant physical strain or intermittent severe strain.	41–50

FIG. 1. Degree Definitions for Physical Effort. (The Brewster Variation of the A. L. Kress Plan)
From: C. W. Lyttle, Job Evaluation Methods
2nd ed. New York 1946, Ronald Press Company, p. 97

human effort but there were some tangible physical components that could be measured, hoping that they be relevant to the energy requirements. Such things as: weight lifted, distance carried, number of occurrences per day, etc. were combined into some algebraic formula. The numerical results of these manipulations were then used to estimate the point rating for the physical effort requirements with the help of some arbitrary scale.

These methods shall be discussed in some detail later; at this moment we shall concern ourselves only with the fact that such arbitrary and absolute unscientific methods *are used* by intelligent men and engineers. This alone seems evidence enough of the search for something—almost anything—that might lend *scientific support* to those verbal definitions.

A European job evaluation system (3) termed these physical job requirements *work resistance*—a very picturesque title! What is to be understood by this may be gathered from the words and explanations of Figure 1, or from any one of a dozen similar tables of definitions (14). The fact remains, however, that we are trying to analyze with such words as "little," "medium," "considerable" and "high" an almost unlimited variety of jobs performed under a great number of totally different conditions.

Just what is "little physical effort," and what is "considerable physical effort"? It seems indeed understandable that so many attempts have been made to find some measureable dimensions for human energy expenditure that may permit a better rating and understanding of this component of industrial work.

TECHNIQUES OF ENERGY (EFFORT) MEASUREMENTS

Almost every technique of "technical measurement" of energy expenditure belongs to either one of four categories:

1. Straight output measures
2. Fatigue measurements
3. The physiological system
4. The mechanical-physical system.

All of these techniques have been tried for specific applications to human energy expenditure in industry by engineers and psychologists from Taylor and the Gilbreths to modern work measurement systems. We shall briefly describe how they were applied to the problem of finding a measuring scale for physical effort and what their contributions have been to our knowledge of work.

STRAIGHT OUTPUT MEASURE

This is the system known as piece work. It was intended to properly reward *additional effort,* rendered over and above some standard or minimum performance. While it never actually claimed to be a *measure of effort or energy expenditure,* high piece work performance too often became synonymous with high effort. This was a typical interpretation by line supervision.

The mere count of the tangible number of pieces produced by the worker during the day does not tell us very much about energy expenditure. It has no application at all to such results of effort which, due to their nature, cannot be expressed by time consumption. If honorable and fair reward is the objective, the formula: $\frac{\text{Quantity}}{\text{Time}}$ is no longer considered the sole basis for determining proper remuneration.

FATIGUE MEASUREMENTS

Fatigue measurements and the introduction of fatigue allowances were the first step to understand the complex human contributions to some counted output. For a while, Industrial Engineers were inclined to believe that this was the answer to their problem.

This somewhat hasty enthusiasm developed since in the beginning jobs with a fairly high degree of physical exertion were so investigated. Early fatigue measurements followed the pattern of counting the number of pieces produced during each consecutive hour of the working day and developing a fatigue curve.

As long as jobs of fairly exhaustive nature were studied, some significant drop in hourly performance could be observed. Fortunately, such jobs are rare in modern industry. It was soon apparent that under conditions requiring less than near-to-capacity physical effort, the form of such curves was determined by incentive or motivation more than by fatigue (5), (16). Thus, in spite of different internal efforts rendered, the same accomplishment per unit time appeared at the beginning and at the end of the day. This approach, therefore, tended to hide rather than disclose the real amount of energy expended by the individual.

Psychologists and Industrial Engineers, somewhat independently came to the conclusion that output decre-

ment was not a good index of fatigue. Due to its many subjective aspects, fatigue was not even a good measure of energy expenditure. Yet, the subject remained intriguing to those interested in the science of work and numerous sophisticated methods of fatigue measurements were developed, such as measurements of changes in capacity for simple reasoning tasks before and after strenuous work, or susceptibility to optical illusions after periods of high energy expenditure, to name only a few. Regardless of *how good we may get* in measuring both the subjective and objective aspects of fatigue, we would still only be measuring *effects* and from them make *inferences* on the cause: the energy expenditure originally required on the job.

THE PHYSIOLOGICAL SYSTEM

Physiological measurements represented a more direct attack on the phenomena of energy expenditure in human work.

One of the earliest approaches to physiological measurements is known as the CO_2 method. Atzler (4) and other pioneers in the field (9) attempted to obtain reliable knowledge about human energy expenditures by measuring the amount of oxygen converted into carbon dioxide. Oxygen is quickly consumed in the body and doing any kind of work, whether within the definition of physics and mechanics or otherwise, will immediately cause an increased activity of the breathing apparatus over and above the basal metabolism, which is some minimum oxygen conversion when perfectly at rest.

The method provided extremely valuable information on the energy efficiency of certain prototype jobs. Less fatiguing and safer methods for metal filing, crank turning, pushing of wheelbarrows and weight lifting were developed. The design of hand tools is likewise indebted to these studies (2), (4), (10).

Because of its rather complex equipment the method remained in the laboratories and never became really practical for industrial applications. Physiological measurements can hardly be justified for a mere quick check to determine which one of several similar jobs actually requires the greater physical exertion.

THE MECHANICAL-PHYSICAL SYSTEM

This is also known as the c-g-s system from the dimension used to express force, work and energy in the pure sciences: centimeter, gram and seconds, commonly known as the foot-pound system.

"Work" is defined as Force $\times$ Distance (where distance is to be measured in the direction of the force vector) and "energy" is defined as work performed in a specified time (foot-pounds per second, minutes or hours).

These very definitions limit this system's application to human work. Loads carried or transported by men are usually moved perpendicular to the direction of the external force, gravity. Thus, the product of "weight" and "distance carried" has actually no mechanical meaning.

The majority of industrial "effort requirements" are tasks equivalent to carrying loads. The energy expenditure stems from the static support work that has to be done. Energy must be expended and fatigue would occur even if no distance were covered and no work at all would be performed in the straight mechanical sense.

The mechanical work formula must be modified in some way before it can be applied to human work (19). The problem is that of finding *some additional factor* that will make sense to the *human motor*. This factor has been called the *factor of static-dynamic equivalence* (16). As yet we do not know what this factor of static-dynamic equivalence might be.

In spite of this difficulty, or perhaps because other measuring approaches involve equally serious complications, some "neat" applications of the basic laws of mechanics have found their way into the Industrial Engineer's kit. Time and again it has been tried to fit them to human work, perhaps as a supplement to our verbal definitions of physical effort requirements (Figure 1). Sometimes they are *used as an aid* to our judgment of effort ratings; sometimes, however, as a substitute.

RELIABILITY OF MECHANICAL "EFFORT FORMULAE"

That different variations or modifications of the "mechanical work" formula, when applied to human energy expenditure, will yield different numerical results comes as no surprise. This in itself does not yet mean that such formulae are useless. The job evaluation system which employs such formulae for estimating physical effort uses (or should use) the numerical result of such *computed effort* mainly to *rank the jobs of a plant into some proper order* with respect to physical effort requirements. The effectiveness of various effort formulae will be judged by a concept known to psychologists as *reliability:* the asurance that our measurements are *precise* (as opposed to accurate), and that we will obtain about the same results with equivalent forms of measurement. For industrial purposes "result" means some rank-order of effort requirements in our jobs which is acceptable to Industrial Engineering objectives.

The problem therefore is: can a rank-order of physical effort requirements that is *consistent with other rating methods* be obtained by the use of various semi-mechanical formulae employing the directly measurable components *weight, distance* and *time?*

To answer this question, one has only to compute the energy expenditure of some well described sample of industrial jobs in all systems under investigation, to compare the results with each other and with the ranking obtained by rating judgments based on some such set of definitions as listed in Figure 1.

The job sample should fill certain requirements:

1. Jobs should be representative of the type of physical effort involved in industrial work.
2. Distances, weights and time must be easy to determine.
3. Dynamic work, i.e., *moving* of weights should be blended with static work, i.e., *holding* of weights.

No.	Job Details	Single Weight Handled	No. of Cycles p/shift	Total Turnover of Goods	Distances	Total "Work" in	Average "Energy" per man
		lbs.		lbs.	feet	ft. lbs.	ft.-lbs./min.
1.	REMOVING CHIPS IN WHEELBARROW						
	Rolling & holding resistance = 22.4/C	Shovel					
	Loading w/shovel: 40 W-barrows at 213 lb.	(15.4)		8,520	3.3	28,120	
	Pushing full = .224 × 308 =	69	40		207.0	571,320	
	Pushing empty = .224 × 95 =	21	40		207.0	173,880	
	Unloading Steel Turnings w/shovel			(2,200)	8.2	18,040	
						791,360	1,649
2.	CENTERING SHAFTS	32	320	10,240	19.7	201,730	420
3.	DRILLING ¼" in Generator Housing	24.6	240	5,900	3.9	23,260	48
4.	TAPPING ¼" Thread	24.6	480	11,800	5.0	59,000	123
5.	THREAD CUTTING on Lathe	24.6	160	3,940	13.1	51,600	107
6.	SAND MOLDING on Molding Machine	118	92	10,860	16.4	178,040	371
7.	CHARGING BLAST FURNACE (3 Men)	Raw Iron					
	Loading in Buggies: 71 Charges at 810 lb.	(94.6)		57,500	4.3	245,200	
	Pushing full: 1st station, drawbar pull	44	71		24.6	76,900	
	Pushing full: 2nd station, drawbar pull	77	71		85.3	466,300	
	Pushing empty: drawbar pull	33	71		32.8	76,800	
					3 Men	865,200	
					1 Man	288,400	600
8.	POURING MOLTEN METAL (10 Men)	Ladle					
	Total Weight poured w/Hand Ladle	(96.4)		24,200	29.5	713,900	
	Full Car Ladle (5 men), drawbar pull	121	27		110.0	359,400	
	Empty Car Ladle (4 men), drawbar pull	22	27		110.0	65,300	
					10 Men	1,138,600	
					1 Man	113,900	237

FIG. 2. Elements of Physical Effort Requirements for 8 Jobs: Weights, Distances and Work.

4. As well as can be estimated, jobs with both "low," "medium," and "high" physical requirements should be represented.

Jobs which fill these requirements are certainly plentiful in any manufacturing industry. The reader should, therefore, have little difficulty in applying the principles of the following study to his own operations. He may even reach somewhat similar conclusions about these formulae as will be represented here.

For the purpose of illustration, and mainly to explain the approach and the theory behind some of the various formulae in use, the author conducted such a reliability study with a sample of eight jobs chosen from foundry and metal shop operations.[1]

This does not mean that such formulae for physical effort are confined to the metal trade. Effort formulae are used in many industries. As a matter of fact, one of the formulae presented originated with one of the country's largest chemical manufacturing concerns.

All jobs in our sample were carefully analyzed and complete job descriptions were prepared. The collection of descriptive data on the job sample of this case study went far beyond what is ordinarily done in the course of a job evaluation program. Difficulties encountered by the Job Evaluation Committee in assessing a proper rating of physical effort actually sponsored this particular investigation. The jobs are listed in Figure 2.

[1] The data originated from a medium-sized metal working industry close to the Dutch-German border where the author began his research on the use of effort formulae.

DETERMINATION OF DISTANCES AND WEIGHTS

Figure 2 also is a summary of the measurements that enter into the various effort formulae. The drawbar pull required to pull the furnace buggy and the car-ladle were determined by an automatic dynamometer. The instrument, connected between the workers and the cars they pulled recorded a diagram of the varying force necessary to start the movement of the load and to keep it moving. The detailed data for this portion of the physical effort in Job Nos. 7 and 8 are based on a number of such measurements under various conditions. The rolling and lifting resistance for Job No. 1 "Removing Metal Chips in Wheelbarrow" was determined in a similar way. In all other cases, where materials are transported directly by carrying them, the force required equals the weight of the goods handled.

RESULTS OF JOB EVALUATION

The job evaluation program used a plan with verbal definitions only. The definitions for "small," "medium" and "high" physical efforts were much similar to those of the Kress Plan previously shown in Figure 1.

Job evaluation at the particular plant from which these job examples are reported was the duty of a committee of management and labor representatives.

The pooled average of all individual rating estimates gave the following rank-order of physical effort for our sampling of eight jobs.

Highest:	Removing Chips	45 points
	Pouring Molten Metal	42 "
	Sand Molding	41 "

Rating	Points	Assistant Manager	Chief Engineer	Supervisor A	Supervisor B	Foreman	Labor Representative
Continuous Physical Exertion.—	50				Chips Removal	Sand Molding Chips Removal	Chips Removal Pouring Metal Sand Molding
Heavy Weights, Hard Work With Constant Strain.—	45	Pouring Metal					
	41	Chips Removal		Chips Removal	Charg. Furnace Sand Molding	Pouring Metal	Charg. Furnace
Considerable Phys. Effort, Average Weight Material. Difficult Work Position.	40		Chips Removal Sand Molding	Charg. Furnace Pouring Metal	Pouring Metal	Charg. Furnace	
	35	Sand Molding	Pouring Metal	Sand Molding			
	31	Charg. Furnace	Charg. Furnace				Centering
Sustained Physical Effort.—	30	Centering		Centering		Centering	
Short Cycle Work, Mach. Time = Handling Time.	25		Centering		Centering		
	21					Tapping	Tapping
Light Physical Effort.— Machine Time Exceeds Handling Time.	20		Tapping	Tapping			Drilling
	15			Thread Cutting	Tapping	Thread Cutting	Thread Cutting
		Tapping			Thread Cutting		
	11	Thread Cutting	Thread Cutting	Drilling		Drilling	
Light Work.	10	Drilling	Drilling		Drilling		
Little Physical Effort.	5						

FIG. 3. Results of Job Evaluation Committee Rating.

	Charging Furnace	37 points
	Centering Shafts	28 "
	Tapping on Drill Press	18 "
	Thread Cutting	13 "
Lowest:	Drilling	11 "

Obviously, some individual deviations from the pooled averages are due to varying vested interests of the raters. The labor representatives were, naturally, inclined to rate high to push up wages. Each supervisor rated his "own" jobs high and showed less appreciation for the jobs of the other fellow. The scaled comparison in Figure 3 leaves no doubt as to which jobs were supervised by whom.

But it was not all personal bias that caused discrepancies between raters' judgments. More often such differences were simply due to lack of definition and consequent wide range of interpretation of such words as "light weight material," "sustained physical effort" and the like (see Figure 1). It was not just a case of union members "pushing the ratings up." Figure 3 illustrates this very clearly, too, since it allows a comparison of both relative ranks and absolute values of the committee members' evaluations.

Rating *difficulty* rather than rating *bias* is probably the main reason why some job evaluation systems try to *compute* "physical effort" by a formula rather than to accept a result which is merely the average of a number of individual estimates. Several formulae are in use.

1. *Method of Highest Weight Regularly Handled*

Judging the degree of physical effort by comparison of the actual weights to be handled on the job is a quick and simple method and one which is quite common. Looking at Figure 2, it can be seen that Job No. 6 (Sand Molding on Molding Machines) would be rated highest for physical effort among our eight sample jobs (118 lbs). The job ranking next in physical effort would be No. 8 (Pouring Molten Metal) (96.4 lbs) and so on. (Figure 4.)

Job Title	Maximum Weight lbs.	Rank
6. Sand Molding	118	Highest
8. Pouring Molten Metal	96.4	
7. Charging Furnace	94.6	
1. Removing Chips	69.0	
2. Centering Shafts	32.0	
3. Drilling on Drill Press 4. Tapping on Drill Press 5. Thread Cutting	24.6	Lowest

FIG. 4. Ranking of 8 Jobs for Physical Effort by Method of Maximum Weight Handled.

Job Title	Goods Turnover lbs.	Rank
7. Charging Furnace	19,116	Highest
4. Tapping	11,800	
6. Sand Molding	10,860	
2. Centering Shafts	10,240	
1. Removing Chips	8,520	
3. Drilling	5,900	
5. Thread Cutting	3,940	
8. Pouring Metal	2,420	Lowest

FIG. 5. Ranking of 8 Jobs for Physical Effort by Method of Total Goods Turnover.

2. *Method of Total Turnover of Goods*

Some companies prefer to rate physical effort from the total quantity of goods the worker actually handles during the day. They feel that this is a relatively fair measure of the man's contribution to the business of the company, as far as physical effort is concerned. The formula mentioned in the previous paragraph is thus extended by the *number of pieces* the workman has to handle. Repetitive handling of the same piece of material, however, is only considered as one handling. (Figure 5.)

3. *Mechanical Work Formula*

Contrary to system 2.—Total Goods Turnover—other systems favor the principle that if an object is handled in and out of a machine, it is handled twice. This thought is then combined directly with the principles of mechanics and physics, in which "work" is computed in ft. lbs. ∴

No. of cycles × distance × weight = Effort/day

For this computation see also Figure 2. The ranking of the eight jobs when determined by this method becomes again a different one. See Figure 6.

4. *Method of Suppressed Distances*

The series of formulae, principally based on the elementary units of the mechanical measuring system, would be incomplete without mentioning a special modification thereof. Some companies have done a great deal of research on their own before adopting a job evaluation system suitable to their needs. Although little is published on such private investigations it may be assumed that some criticism was raised against the application of the straight mechanical formula in "foot-pounds."

The possibilities of injuries, strained muscles, has to be taken into account according to the particular circumstances. Factors were thus developed to modify (mostly to increase) the effort computed in "foot-pounds" according to the possibilities of such strain. One such method applies the principle of additivity. The number of points for physical effort (as computed from a formula) are increased by additional points to acknowledge basic physical strength requirements needed to lift the required weights in the first place. Having made provision for these strength requirements one may reason that there is almost no limit to the distance over which a man can carry small and medium weights. In these cases, effort figures should not be unduly inflated by the mere walking distance.

The solution to this problem is sought by decreasing the distances which were to enter into the formula. Instead of actual distances involved in the plant operations, such systems use a factor, for example:

0-4	feet:	use	Factor	1.0
5-10	"	"	"	1.5
11-25	"	"	"	1.75
26-50	"	"	"	2.0
over 50	"	"	"	2.5

The formula would then read:

No. of cycles × (factor) × weight = Effort

instead of:

No. of cycles × distance × weight = Effort

This modified mechanical formula for computation of the physical effort involved in our eight jobs gives the ranking ladder in Figure 7.

DISCUSSION

Five different methods of measuring the physical effort of eight jobs were demonstrated. Five different answers resulted. Inter-system reliability of these methods is poor. Figure 8 illustrates the differences between these five results. Depending on the formula used, four different jobs claim the rank of "highest physical effort." The rankings of the subsequent jobs also depend on the formula used and many of the results so obtained do not agree with the general trend of estimates of a Job Evaluation Committee. Formulae-rating reliability is, thus, also poor. Not only is the sequence of ranks continually re-

Job Title	Worki n "Foot-pound"/ min.*	Rank
1. Removing Chips	1,649	Highest
7. Charging Furnace	600	
2. Centering Shafts	420	
6. Sand Molding	371	
8. Pouring Metal	237	
4. Tapping	123	
5. Thread Cutting	107	
3. Drilling	48	Lowest

* These inappropriate foot-pounds shall throughout this paper be designated as "foot-pounds"

FIG. 6. Ranking of 8 Jobs for Physical Effort by the Mechanical Work Formula.

Job Title	Effort = No. × factor × weight	Rank
2. Centering Shafts	30,700 lbs.*	Highest
7. Charging Furnace	29,410 lbs.	
1. Removing Chips	25,555 lbs.*	
4. Tapping	23,600 lbs.	
6. Sand Molding	19,000 lbs.	
3. Drilling	11,800 lbs.	
5. Thread Cutting	11,800 lbs.	
8. Pouring Molten Metal	10,450 lbs.	Lowest
* *Computation:*		
Job No. 1: *Removing Chips*		
775 shovels × 15.4 lbs. × 1.0 (factor for 3.28 ft.)	= 11,935 "foot-pounds"	
40 trips × 69 lbs. draw. pull × 2.5 (factor for 207 ft.)	= 6,900 "foot-pounds"	
40 trips × 21 lbs. draw. pull × 2.5 (factor for 207 ft.)	= 2,100 "foot-pounds"	
200 shovels × 15.4 lbs. × 1.5 (factor for 8.2 ft.)	= 4,620 "foot-pounds"	
Job No. 1: Total	= 25,555 "foot-pounds"	
Job No. 2: *Centering Shafts*		
Total distance of movement in over-all cycle	= 19.7 feet	
Place shaft on machine 320 pcs. × 32 lbs. weight × 1.50 (factor for half distance)	= 15,350 "foot-pounds"	
Remove shafts from machine 320 pcs. × 32 lbs. weight × 1.50 (factor for half distance)	= 15,350 "foot-pounds"	
Job No. 2: Total	= 30,700 "foot-pounds"	

FIG. 7. Ranking of 8 Jobs for Physical Effort by Method of Suppressed Distances.

Rating Scale		1. Method of Max. Weight Regularly Handled	2. Method of Total Goods Turnover	3. "Energy" Measurement ft.lbs./day	4. ft.lbs./day with suppr. Distances	Verbal Definitions of Job Eval.	Scale
Highest Physical Effort	100%	Sand Molding	Charging Furnace	Chips Removal	Centering Charging Furnace	Chips Removal Pouring Molten Metal Sand Molding	100%
	90%						90%
Hard Work		Pouring Metal Charging Furnace			Chips Removal	Charging Furnace	
	80%						80%
					Tapping		
Consid. Effort	70%						70%
			Tapping on Drillpress		Sand Molding	Centering Shafts	
	60%						60%
		Chips Removal	Sand Molding Centering				
Average Effort	50%						50%
			Chips Removal				
	40%					Tapping on Drillpress	40%
				Charging Furnace	Drilling Thread Cutting Pouring Molten Metal		
Light Effort	30%		Drilling				30%
		Centering		Centering		Thread Cutting	
			Thread Cutting	Sand Molding		Drilling on Drillpress	
	20%	Drilling Tapping Thread Cutting					20%
Little Effort			Pouring Molten Metal	Pouring Molten Metal			
	10%						10%
Lowest Physical Effort				Tapping Thread Cutting Drilling			

FIG. 8. Relative Ranks of 8 Jobs in Respect to Physical Effort when Effort is Computed by 4 Different Methods and when Rated by Job Evaluation.

arranged like a freshly shuffled deck of cards, but the application of each individual formula also alters the *relative value* of the rating.

The sole objective for using an "effort formula" is that of *providing an aid to subjective ratings*. Even though these ratings may not give a very good estimate of actual human energy expenditure they *are* the reliability measure we are dealing with in the present context. As the

results of some formulae completely lose resemblance to the ratings of a job Evaluation Committee they are no longer an aid.

In spite of the difficulties in estimating any concept by a scale of mere verbal definitions, a job evaluation committee acting in good faith will not permit its work to be discarded as completely incorrect. They may be willing to let a formula *adjust some ratings* on which the committee could not agree, or may depend on it in borderline cases. However, no formula which does not follow the general pattern of the rater's judgment will ever be accepted as being "better" than their best estimate. Job No. 8: Pouring Molten Metal is, without a doubt, a job requiring hard work and high physical exertion. Any challenge to this rating could quickly be disposed of by having the challenger try the job himself. Three methods of computation, however, brought out results by which the job was rated as having "little effort" or "work requiring light physical effort." Obviously these are cases in which the formula will only be confusing.

At this point the author and his Job Evaluation Committee began to manipulate the formula to see whether they could not come up with something that would better agree with their judgments. They were surprisingly lucky. Not only did they come up with an estimation formula that *"felt right"* like any decent rule-of-thumb should (*face validity*), but the new formula is consistent with at least one well known theoretical principle: the exponential character of the effort phenomenon.

The reason that the formulae discussed above do not accurately measure physical effort lies in the different significance of the two main factors that enter such formulae: distances and weights.

SIGNIFICANCE OF DISTANCES AND WEIGHTS

When using the Straight Mechanical Formula in "foot-pounds," Job No. 1 (Removing Chips in Wheelbarrow) ranks far above all other jobs. It can be seen from Figure 2, that the reason for this is not the load handled but the relatively long distance of travel (207 feet). The product: *Distance* $\times$ *weight* is, therefore, high. When using the modified mechanical formula with suppressed distances, Job No. 1 again ranks fairly high, although this time for a different reason: namely, an unusually great number of occurrences in one particular element of the job (775 shovels/day). The product: *number of cycles* $\times$ *(distance factor)* $\times$ *weight* is therefore again high. Thus the emphasis on the job component that causes the high rating has shifted with the formula used for computation.

From these observations one conclusion might be drawn: *a correct concept of Physical Effort cannot be obtained from any linear mathematical function nor from any mathematical product in which all factors are of equal status and importance.*

One of the factors in the effort formula probably ought to have greater significance and more influence than the others. The factor which ought to be so emphasized, is the *load or weight*. Weights affect the human metabolic efficiency more than do distances or even the speed of work as measured by the number of cycles per hour (21). It is, necessary to *incorporate* into the effort formula a fatigue allowance, to which the human body—as opposed to a machine—is entitled, rather than adding such an allowance afterwards to results which were first obtained *without* considering fatigue.

When using the basic mechanical formula, an effort-figure equivalent to 3,000 "foot-pounds" is performed by a man who carries a suitcase weighing 30 lbs. over a distance of 100 ft. Not a difficult task! The same amount of effort would be computed by this formula if he carried 300 lbs. over a distance of 10 feet or if he moved 1,000 lbs. just 3 ft. One is quite an athletic feat and the latter is impossible! This is due to the greater sensitivity of the human body to weights than to distances (19). If someone were requested regularly to do such things, the effort requirements would have to be rated higher than in the "suitcase job."

THE EXPONENTIAL FORMULA

The chances for useful computations of physical effort by a "sort of" mechanical formula *may be enhanced* if greater significance is allotted to the factor weight in the effort formula. This can be achieved by changing the mere product of cycles, distances and weights to an exponential formula in which weight *is raised to a power*. The dimension for physical effort may thus become: ft. (lbs.),[2] ft. (lbs.),[3] of ft. (lbs.).[4] To determine which exponent to choose: 2, 3, or 4, or any fraction of a whole number, some comparisons will have to be made between the results obtained with any one of these tentative exponents. The validity of these results will have to be judged in terms of the same criterion used before: the capacity of any given formula to rank a certain sample of industrial jobs for physical effort in approximately the same order as they might be ranked by judgment ratings. A validity of another kind namely, the capacity for such a formula to express physical effort *correctly* in terms of other independent measures of energy expenditure should perhaps also be explored. The latter might be called *absolute validity* while the former may be called *operational validity*.

THE EXPONENT AS STRAIN FACTOR

Such a new formula would not yet be universal. It would still not be applicable to straight static work where loads are held still and the distance is zero. But such jobs are rare in industry and although much holding is involved in all industrial jobs it is usually accompanied by a movement or transport of the load. By raising weight to a power in the effort formula it might be possible to emphasize the real "job difficulty," thus getting closer to the

necessary static-dynamic equivalence concept mentioned earlier.

Before going ahead with such a strain factor, however, let us examine what consideration, other than emphasis of weights alone, could be appropriate. There are three measurable components from which we hope to compute physical effort in a quantitative way. These are: the *weight handled*, the *distance involved*, and the *frequency* of occurrence during a day, hour, or any other appropriate period that enables us to include the essential element of *time* or *speed of action* in the formula.

Next to weights we may wish to distinguish between various *kinds of distances*. Looking back at our example of the job that consisted of carrying a suitcase of 30 lbs. over a distance of 100 feet, we may imagine that the suitcase instead of being carried 100 feet had to be hoisted 100 feet up with a rope and pulley. Intuitively, this would strike us as requiring more effort than just walking with it. Some of the early physiological experiments, while not exactly comparable, seem to bear out the fact that "lifting up" is harder than "walking alone" (19). For this reason we may wish to add a factor to distances if they are in the direction of "up" rather than horizontal. Say we may want to double this *kind of distance*. Hoisting a weight up is harder mainly because the motions involved are again more of a static nature; most of our effort is spent *holding* the rope and with it the weight.

Research into these possibilities would certainly be desirable. Whether such breakdown into various types of distances would still be practical for industrial use is another question that cannot be answered here. The important thing to keep in mind is that we need some measure of the *ratio* of static work to dynamic work or that *we need to make some assumptions of what this ratio might be in industrial work*. As will be seen, such assumptions were made and the effects of varying ratios of static to dynamic work were considered in the course of some experimental tests on "absolute" validity of the new formula. With this in mind, an attempt was made to determine the likely exponent "x" in the new effort formula, Eq. 1.

$$E = n \cdot d \cdot w^x \qquad \text{Eq. 1.}$$

where
E = Effort
n = Number of cycles per unit time.
d = Distance over which w is moved or carried.
w = Weight, i.e. actual load, drawbar-pull, etc.
x = Strain factor (or static-dynamic-equivalence)

Tentatively the exponents 1.5, 1.8, 2, 2.5, 3 and 4 shall be used to compute the physical effort of the same sample of eight industrial jobs dealt with previously. In order to compare the results with those of the straight mechanical formula, the exponent $x = 1$ is also included.

It will be necessary to analyze the various elements of these eight jobs and to compute them separately. When using the straight mechanical formula in "foot-pounds," for example, in Job No. 1: (Removing Chips), it made no difference whether the total weight of goods turned over (8,520 lbs.) was multiplied by the average shoveling distance (3.3 feet) or whether the effort requirements were composed of 775 shovel loads at 11 lbs. each. Everyone of the 8,520 lbs. had to be lifted over the same distance and in a linear product factors may be exchanged, combined or split. When switching to powered weights, however, *work methods* in the individual elements of the various jobs must also be considered.

Wherever a job is made up of different elements of physical activity, the total effort requirements are *assumed* to be the sum of the individual requirements of the job elements.[2]

EFFORT TRANSITION POINT

Another consideration when using an exponential formula is the proper choice of a *unit* for the weights handled. The main objective with the new formula is *emphasis;* emphasis on what is believed to be of significant influence on human effort. It would not be logical to use *one pound* as the measuring unit of weights. 1^2 and 1^4 is still only 1 and besides, it is known that small weights such as one, two or five pounds are of no real significance. Handling or transporting such small weights is not a physical effort as considered within the framework of most of our evaluation measures.

The lack of effort in handling such small weights is also confirmed through experiments with the CO_2 measurements of energetic effort. It was found that oxygen consumption for the job of lifting light weights underwent little change at first although weights were gradually increased until a certain transition point was reached or passed. From there on the oxygen consumption would increase extremely rapidly with increased loads. This threshold would vary, of course, depending on the physical condition of the person performing the test. However, in most cases a rapid increase in oxygen consumption was observed when weights exceeded approximately 10 kilograms. (10 kilograms = 1 deca-kilogram = 22 pounds.)

This figure of 22 lbs. will not be unfamiliar to many of our Industrial Engineers. Frederick W. Taylor arrived empirically at this figure when investigating optimal shovel loads. The optimal shovel load as found by Taylor was 21½ lbs. (24).

The unit of Weight (w) in the exponential effort formula may therefore tentatively be chosen as *one deca-kilogram or 22 lbs.* It is, however, suggested that further research with, for example, the CO_2 method may provide more knowledge on the position of the "effort transi-

[2] The assumption that effort requirements are additive is made in analogy to the statistical concept of additive probabilities. The probability that an event (in our case a certain degree of fatigue or exhaustion) will occur in one of several ways is the sum of the probabilities of the occurrence of the several different possible ways (job elements).

Description of Jobs (or Job-Elements)	Measured Elements			Converted Units			Effort—Computation with The Exponential Formula: $E = n \times D \times W^x$						
	Distance d	Weight w	Cycle per day n	Distance D	Weight W	Cycle p/hr. n	Effort per Hour						
	feet	lbs		meter	dkg		$x=1$	$x=1.5$	$x=1.8$	$x=2$	$x=2.5$	$x=3$	$x=4$
1. Removing Chips in W/barrow													
a) loading with shovel & fork	3.3	15.4	775	1.0	.70	96.8	68	57	51	47	39	33	23
b) transport full wheelbarrow	207.0	69.0	40	63.1	3.14	5.0	990	1,754	2,470	3,108	5,512	9,768	30,670
c) transport empty wheelbarrow	207.0	21.0	40	63.1	.95	5.0	300	293	287	284	278	270	256
d) unloading with shovel	8.2	15.4	200	2.5	.70	25.0	44	37	33	31	26	21	15
Total							1,402	2,141	2,841	3,470	5,855	10,092	30,964
6. Sand Molding on Molding Mach.	16.4	118	92	5.0	5.40	11.5	310	722	1,197	1,679	3,896	9,054	48,893
8. Pouring Molten Metal													
a) pouring from hand ladle	29.5	96.4	49	9.0	4.38	6.1	240	503	784	1,054	2,204	4,613	20,205
b) transp. full carladle	110.0	24.2	13	33.5	1.10	3.2	118	126	130	132	138	146	160
c) transp. empty carladle	110.0	5.5	13	33.5	.25	3.2	26	12	8	6	4	—	—
Total							384	641	922	1,192	2,346	4,759	20,365
7. Charging Blast Furnace													
a) loading pig iron by hand	4.3	94.6	71	1.3	4.30	8.9	50	103	159	213	441	914	3,922
b) loading risers by pitchfork	4.3	15.4	500	1.3	.70	62.5	57	47	43	40	33	28	19
c) loading scrap iron by hand	4.3	33.0	213	1.3	1.50	26.6	52	64	72	78	95	117	175
d) transp. buggy, full, station 1	24.6	14.7	71	7.5	.67	8.9	44	37	33	30	25	20	13
e) transp. buggy, full, station 2	85.3	25.7	71	26.0	1.16	8.9	268	291	300	310	326	349	416
f) transp. empty buggy	32.8	11.0	71	10.0	.50	8.9	44	30	26	22	15	12	5
Total							515	572	633	693	935	1,440	4,550
2. Centering Shafts on Lathe	19.7	32.0	320	6.0	1.45	40	348	420	468	500	607	732	1,061
4. Tapping on Drillpresses	5.0	24.6	480	1.5	1.12	60	101	107	111	113	120	126	141
5. Thread Cutting on Lathe	13.1	24.6	160	4.0	1.12	20	90	95	98	100	106	112	126
3. Drilling on Drillpresses	3.9	24.6	240	1.2	1.12	30	40	43	44	45	48	50	57

FIG. 9. Effort—Computation with The Exponential Formula.

tion point" and on factors that influence it. It seems to be a generally recognized fact that an invisible boundary *does exist* somewhere between negligible effort requirements and those which are no longer negligible.

RESULTS OF EFFORT COMPUTATION WITH THE EXPONENTIAL FORMULAE

Effort requirements for the eight jobs analyzed in Figure 2 were computed using an exponential formula that raised the weight to various powers (see Figure 9). The result of these computations using several values of x are plotted on a logarithmic scale in Figure 10.

As can be seen from Figure 10, the relative ranks of the eight jobs with respect to their physical effort shift immediately as the exponent "x" is assigned values greater than one; in other words, as the factor "weight" in the effort formula is emphasized above the value with which it entered into the straight mechanical formula. But from there on, the relative rank position seems established and does not change for a certain range of exponents (from $x = 1.5$ to $x = 3$) until, with further increasing emphasis of the weight handled, Job No. 6 (Sand Molding) takes the leading position in effort requirements over Job No. 1 (Chips Removal).

In the neighborhood of $x = 2$ (heavy vertical line in Figure 10) the eight jobs have a relative rank which is almost identical to the averaged ratings of the Job Evaluation Committee. By superimposing the point scale (Figure 1) from the verbal definitions of physical effort requirements into Figure 10 the following comparison can be drawn:

No: Job Title	Job Evaluation Committee Rating Points			Computation with Exponential Formula (Converted to Pts.)	
	From:	To:	Average:	$x=1.8$:	$x=2$
1. Chips Removal	40	50	45	48	49
6. Sand Molding	35	50	41	42	44
8. Pouring Metal	38	50	42	39	42
7. Charging Furnace	31	42	37	36	37
2. Centering Shafts	25	32	28	33	32
4. Tapping	13	22	18	21	21
5. Thread Cutting	11	15	13	20	20
3. Drilling	9	16	11	13	14

There seems to be a fairly good agreement between effort requirements as computed by the exponential formula and the pooled estimates of the raters. A discrepancy occurs between Jobs No. 6 and 8. Their ranks are transposed from those estimated. Most of the raters were subconsciously influenced by the additional heat conditions under which Job No. 8 (pouring Molten Metal) was performed. Although the factor "disagreeableness" was supposedly rated separately, duplication occurred unintentionally, and credit for the extra heat conditions might have been given twice. This is known as "halo-effect" and is a well known psychological phenomenon in all types of ratings based on subjective human judgment. A high rating on one factor tends to produce high ratings on other factors as well. Halo-effect is particularly crucial in the process of job evaluation and the problem has received considerable recognition in the literature (12).

Agreement between the results of a formula in which weight is raised to the second power and rater's judgment is, of course, no proof that the computation is "scientific" nor even that it is "right," in terms of absolute validity. It is merely a proof that "it works." The fact that many of the raters participated in the development of this formula may have been just as conducive to general acceptance as the "successful" correlation of this small sample with results obtained by previous rating.

However, the development of this formula had more than local shop significance. The company applied it to many other operations in various shops and the formula "did work" where others seemed to fail. It became a simplified tool for middle management, supervisors, and foremen.

The discussion above seemed to show that the new formula has rater validity. It was felt, however, that some experimentation had to be done that would allow at least some estimate of its absolute validity. An attempt was thus made to determine by an independent way the actual value of the strain factor which appears as an exponent of the weight in the formula. An independent measure of the actual energy expenditure by, for example, the CO_2 method was not possible. An independent measure of the possible *effect and range* of human energy expenditure, however, was feasible. With these two objectives in mind the following experiment was made: two jobs, both requiring sustained physical effort and similar in all phases of performance were artificially designed:

Test Job 1: would involve a large weight to be carried over a small distance, and

Test Job 2: would involve a small weight to be carried over a long distance.

Assuming, temporarily, that a strain factor of 2 is a nearly correct figure, i.e., that "weight" affects human effort requirements in the second power, the test conditions were arranged in such a way that

$$\text{distance}_1 \times (\text{weight}_1)^2 = \text{distance}_2 \times (\text{weight}_2)^2.$$

Provided the above assumption is nearly correct and both test jobs are carried out to complete exhaustion, it can be expected that the *number of cycles* "n" which are observed before complete exhaustion occurs should be the *same* in both test jobs. Should, however, the experiment prove the number of cycles not the same, it would be possible to solve for the correct exponent "x" from the test results.

The "effort requirements" in both test jobs are considered identical;[3] namely, efforts which result in complete exhaustion.

It is recognized that there is considerable evidence that exhaustion physiologically is not a universally fixed point of reference. Effects on the organism in completing motor movements to exhaustion are dependent on task and conditions. For two very similar tasks, however, the assumption of identical "effort" may be justified (19).

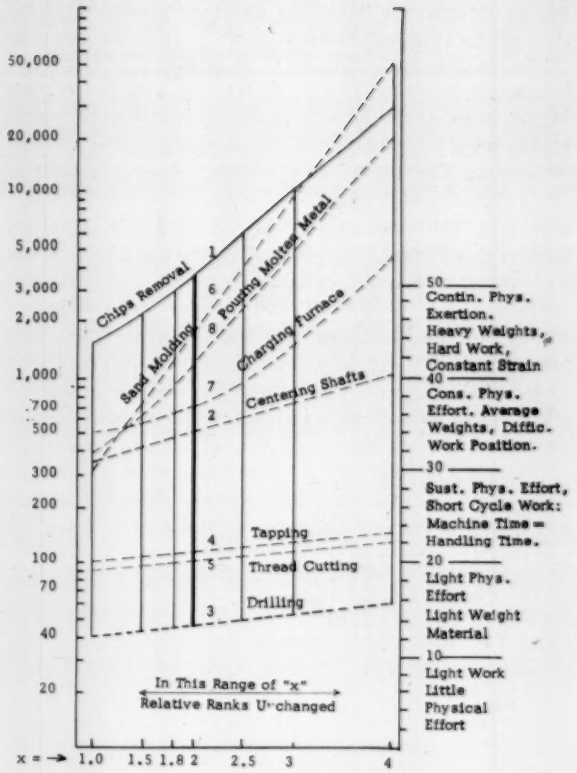

FIG. 10. Relative Ranks of 8 Jobs for Physical Effort Computed as: $E = n \times D \times W^x$.

Test Job 1: $$\frac{n_1 \cdot D_1 \cdot W_1^x}{t_1} = E_{ex}$$

Test Job 2: $$\frac{n_2 \cdot D_2 \cdot W_2^x}{t_2} = E_{ex}$$ Eq. 2.

E_{ex} = effort resulting in complete exhaustion;
n = number of cycles; D = distance (in meters);
W = weight (in units of dkg or 22 lbs.);
t = time (in minutes)

The unknown variable, strain factor "x," can be computed from these two equations.

PROCEDURE

The artificial jobs were representative of actual physical work in industrial plants. They provided for general body fatigue and did not merely affect certain muscles or limbs. Static "work" of holding weights is blended with dynamic "work" in a proportion that seemed in tune with reality. All other conditions were kept as nearly identical as possible in both tests of the experiment.

Thus the test job was chosen as: Picking up a weight

[3] Actually the resultant fatigue is identical; it is here substituted for energy expenditure.

at one station—carrying it a specified distance—setting it down at the next station.

The weight was picked up from a base. This involved bending or stooping. It was lifted straight up and carried in this position to the next base. There it was set down within a marked rectangle. This required some vertical positioning and prevented a simple release of the load when growing fatigue would have made such understandable but undesirable shortcuts likely. At the point of contact a bell would ring indicating the end of *one cycle*. The operator was instructed to start the next cycle immediately and to continue until fatigue and exhaustion would prevent him from reaching the next base. This point would indicate the completion of *one phase*.

At the end of each phase the operator was granted a rest interval. To achieve complete exhaustion, not only at the end of each phase, but also throughout each of the two test series, rest periods between phases were gradually shortened from 13 minutes between first and second phase to 1½ minutes between the last two phases. The test was performed by a plant operator who had volunteered for the job. He was relieved from all other duties for four days and medical surveillance was provided in order to observe safety considerations.

As an experiment the above procedure had several shortcomings that should be recognized: as the experiment was conducted with one subject only, variance introduced by individual differences cannot be measured. As the operator was extremely eager to cooperate and well paid for the job, too, suggestive effects were likely to be present. We do not know what these are. Again, if measurements had been taken with a large number of subjects rather than only one, the influence of the variable "suggestion" might have been less.

Following earlier reasoning in which the different portions of the total distance—lifting, lowering and carrying—were recognized as possible influential variables of their own right, the ratio between one type of "distance" to the other was planned to be kept constant. Lifting distance equaled lowering distance and the ratio "c" between dynamic work and static work in Test Job 1 is: $\frac{0.85}{2.60}$ or 0.327 (Figure 11). It was chosen because one third lifting and two thirds carrying was estimated to be a "good average" proportion between "true" mechanical work and work which does not exactly fit this definition.

While it was possible to keep most of the conditions (operator, time of the day, staggering of pauses, etc.) constant throughout both tests, it proved impossible to keep this ratio between lifting distance and walking distance constant. The operator was not always able to lift the weight to the requested height and failed particularly with increasing fatigue to *hold* it there.

The tables in Figures 11 and 12 record the actual ratio for each phase throughout both tests. The actual ratio is

Exhaustion Test—Job No. 1
(Large weight carried over a small distance)

Weight: $W_1 = 4.17$ dkg (91.74 lbs.) — Carrying distance: 2.60 m (8½ feet)
Base Height: 0.50 m (20″) — Lifting Distance (planned): 0.425 m (17″)
Planned total distance: $D_1 = 2 \cdot 0.425 + 2.60 = 3.45$ meter (11.3 feet)

Planned ratio lifting: carrying $c = \frac{0.85}{2.60} = 0.327$

Phase	Lifting Distance		Total actual Distance D_1	No. of Cycles n	Time per Phase t	Rest Time	actual ratio c_1	Speed: $V_1 = \frac{n_1 \cdot D_1}{t_1}$
	planned	actual						
	meter	meter	meter		Min.	Min.		m/Min.
1	0.85	0.85	3.45	13	1.17	13	0.327	38.33
2	0.85	1.00	3.60	16	1.22	12	0.385	47.21
3	0.85	0.85	3.45	15	1.08	7	0.327	47.92
4	0.85	0.85	3.45	11	0.82	5	0.327	46.28
5	0.85	0.84	3.44	9	0.63	5	0.323	49.14
6	0.85	0.80	3.40	11	0.79	4	0.308	47.34
7	0.85	0.65	3.25	9	0.65	3	0.250	45.00
8	0.85	0.75	3.35	8	0.56	3	0.288	47.85
9	0.85	0.70	3.30	7	0.51	2	0.269	45.29
10	0.85	0.71	3.31	6	0.45	1½	0.273	44.13
11	0.85	0.68	3.28	7	0.50		0.262	45.92

Total Number of Cycles: 112 — Average Distance $D_1' = 3.39$ m
Total Time: 8.38 Min. — Average actual ratio $c_1 = 0.304$

FIG. 11. Exhaustion Test No. 1.

Exhaustion Test—Job No. 2
(Small weight carried over a long distance)

Weight: $W_2 = 2.90$ dkg (64 lbs.) — Carrying distance: 5.20 m (16 feet)
Base Height: 0.07 m (3") — Lifting distance (planned): 0.85 m (33")
Planned total distance: $D_3 = 2 \cdot 0.85 + 5.20 = 6.90$ m (22.6 feet)

Planned ratio lifting: carrying $c = \frac{1.70}{5.20} = 0.327$

Phase	Lifting Distance		Total actual Distance D_3	No. of Cycles n	Time per Phase t	Rest Time	actual ratio c_2	Speed: $V_3 = \frac{n_2 \cdot D_3}{t_2}$
	planned	actual						
	meter	meter	meter		Min.	Min.		m/Min.
1	1.70	2.14	7.34	21	2.26	13	0.412	68.20
2	1.70	1.94	7.14	24	2.39	12	0.373	71.70
3	1.70	1.84	7.04	19	1.84	7	0.354	72.70
4	1.70	1.84	7.04	14	1.36	5	0.354	72.47
5	1.70	1.88	7.08	13	1.21	5	0.362	76.07
6	1.70	1.84	7.04	13	1.22	4	0.354	75.02
7	1.70	1.90	7.10	12	1.11	3	0.365	76.76
8	1.70	1.84	7.04	12	1.13	3	0.354	74.76
9	1.70	1.92	7.12	10	.94	2	0.369	75.74
10	1.70	1.84	7.04	10	.92	1½	0.354	76.52
11	1.70	1.84	7.04	8	.75		0.354	75.09

Total Number of cycles: 156 — Average Distance: $D_3 = 7.08$ meter
Total Time: 15.13 Min. — Average ratio $c_2 = 0.364$

FIG. 12. Exhaustion Test No. 2.

called c_1 and c_2 respectively, while the planned ratio was called "c."

The course of the two tests is reported in these two figures. A total of eleven phases were performed in each test series. The number of cycles per phase decreased as fatigue and exhaustion increased and as the rest intervals between phases were shortened.

Incorporating the deviations from the planned ratio "c" into the formula for the strain factor "x" may be done by way of multiplication as shown in Figure 13.

It will be remembered that the rationale for estimating the exponential strain factor "x" independently from rater's judgment by an experiment was the theory that *for the purposes of job evaluation* the effects of energy expenditure as manifested in fatigue or exhaustion are the variables to be measured under the name of physical effort. As the performance in both test series followed very similar patterns it seemed appropriate to compute "x" by comparing each phase of Test 1 with the corresponding phase of Test 2. The similarity of performance seemed to indicate that the degree of exhaustion was the same in both tests at the end of each corresponding phase.

Before the experiment was commenced it was anticipated that the strain factor would approximate 2. The above experiment confirmed a figure of the order of the one anticipated.

It may also be advisable to use only the last six test results, M_6 to M_{11}, and to ignore the first five phases of the experiment. The accuracy of "x" depending on "complete exhaustion" as the comparable underlying "effort" observed. Complete exhaustion was surely more certain in the latter part of the experiment. The arithmetic mean M_6 to M_{11} is 2.16 and from Eq. 8. in Figure 13 x becomes $= 2.13$.

ABSOLUTE VALUE OF EXHAUSTION TEST "EFFORT"

The same effort computation, which was carried out for the eight plant jobs in Figure 9, can be applied to the two Test Jobs of the experiment. By converting the performance during the test to an hourly basis, a comparison can be drawn between the exhaustive effort of the test jobs and the usually much smaller effort requirements in normal industrial operations.

Example:
Test Job 1

Distance,	$D_1 = 3.39$ meters
Weight,	$W_1 = 4.17$ dkg
Total Cycles,	112
Total Time,	$t_1 = 8.38$ minutes
Cycles per hour,	$n_1 = 800$ (converted)
Average ratio lifting/carrying,	$c_1 = 0.304$
Planned ratio lifting/carrying,	$c = 0.327$
Correction factor,	$\frac{c_1}{c} = 0.929$
Effort,	$E = n_1 \cdot D_1 \cdot W_1^x \cdot \frac{c_1}{c}$

Substituting $x = 1$ and $x = 4$, the following absolute values for the Effort in Test Job 1 are obtained:

$$\frac{n_1 \cdot D_1 \cdot W_1^x}{t_1} \cdot \frac{c_1}{c} = E_{ex} = \frac{n_2 \cdot D_2 \cdot W_2^x}{t_2} \cdot \frac{c_2}{c} \qquad \text{Eq. 3.}$$

n = Number of cycles
D = Distance in meters
W = Weight in dkg
t = Time in minutes
c_1 = Actual ratio lifting/carrying during Test 1
c_2 = Actual ratio lifting/carrying during Test 2
c = Planned ratio lifting/carring
$= 0.327$ = constant

From the above Eq. 3. follows:

$$\frac{W_1^x}{W_2^x} = \frac{\frac{n_1 \cdot D_1}{t_1} \cdot c_1}{\frac{n_2 \cdot D_2}{t_2} \cdot c_2} \qquad \text{Eq. 4.}$$

$$\frac{n_1 \cdot D_1}{t_1} = \frac{\text{Number of cycles} \times \text{Distance}}{\text{Time}} = \text{Speed} = V_1 \qquad \text{Eq. 5.}$$

$$\frac{n_2 \cdot D_2}{t_2} = V_2 \qquad \text{Eq. 5a.}$$

$$\frac{W_1}{W_2} = \text{Weight Constant} = k = \frac{4.17}{2.90} = 1.438 \qquad \text{Eq. 6.}$$

$$k^x = \frac{V_1 \cdot c_1}{V_2 \cdot c_2} = M = \text{Test Results} \qquad \text{Eq. 7.}$$

$$x = \frac{\log M}{\log k} = \frac{\log M}{\log 1.438} = \underline{\underline{6.34 \cdot \log M}} \qquad \text{Eq. 8.}$$

By comparing the 1st phase of Test Job 1 with the 1st phase of Test Job 2; the 2nd phase of Test Job 1 with the 2nd phase of Test Job 2; etc., etc., eleven values for "M" can be obtained. The test results

$$\frac{V_1 \cdot c_1}{V_2 \cdot c_2}$$

for each phase compared are:

$M_1 = 2.242$	$M_5 = 1.735$	$M_9 = 2.294$
$M_2 = 1.471$	$M_6 = 1.821$	$M_{10} = 2.249$
$M_3 = 1.642$	$M_7 = 2.490$	$M_{11} = 2.209$
$M_4 = 1.695$	$M_8 = 1.920$	

Arithmetic mean $\overline{M} = 1.979$
S.D. $(M) = .318$. Confidence Limits $\pm .19$ ($p = .95$, $n = 11$).
Substituting $\overline{M}$ in Eq. 8.:
Strain Factor: $x = 6.34 \cdot \log 1.979 = 1.88$*

* There are, of course, other ways in which the test findings may be used to solve for "x." One other method is described in the text. Neither has it been overlooked that the employed logarithm of the Mean ($\overline{M}$) is not identical to the mean of the log M values ($\overline{\log M}$). For all practical purposes, however, the log function may be considered linear within the small area in question. (For those interested in the difference: x, if computed from: $x = 6.34 \times \log \overline{M}$, comes to $x = 1.84$.)

FIG. 13. Computation of Strain Factor x from Experimental Measurements.

from: $E = 800 \cdot 3.39 \cdot 4.17^1 \cdot 0.929 = 10{,}500$ m dkg/hr.
to: $E = 800 \cdot 3.39 \cdot 4.17^4 \cdot 0.929 = 762{,}000$ m kdg/hr.

This data is plotted for both test jobs on a logarithmic scale with x and E as axes (Figure 14) in the same manner as the eight plant jobs were plotted in Figure 10. The intersection of the curves representing the two test jobs occurs at $x = 1.90$. This is another solution of Eq. 3., based on the over-all result of the experiment rather than on the statistical mean of its single phases.

A comparison as to the order of magnitude between the effort in the exhaustive test jobs and the effort in the normal plant jobs can also be made from Figure 14. In the vicinity of the intersection of the two test curves (where the value for "x" should be correct), the absolute effort value of the Test Job is approximately 40,000 m dkg²/hr. This is more than ten times the effort required in the highest ranking plant job (Job No. 1—approx. 3,000 m dkg²/hr.). If measured on the linear point rating scale, the Test Jobs would rate approximately 50% higher than the highest plant job and nearly twice as high as other jobs which still were termed "Hard Work."

SUMMARY AND CONCLUSION

The results obtained from an ad-hoc experiment, and the agreement which was found to exist between the use of the new exponential formula and committee ratings, indicate that such a modified mechanical formula could be used to compute Physical Effort as an aid to Job Evaluation. Instead of *estimating* how much effort an industrial job may require, a fairly easy computation can be made from the elements: Distance, Weight, and Number of Cycles, if only a special Strain Factor is incorporated in the formula. This strain factor is suggested to be an *exponent of the weight*, and for all practical purposes an exponent of 2 may be used. The distance may be measured in any desired dimension (feet or meters). The number of cycles may be based on any suitable time period such as days, hours or minutes. The *dimension for weight*, however, has a significant bearing on the results obtained. The dimension to be chosen must reflect the transition point between weights which do or do not cause sustained body fatigue. Ten kilograms or approximately 22 lbs. is estimated to be the transition point for average conditions.

The effort figures computed by this formula seem fairly consistent with group estimation of efforts. Absolute validity in terms of true energy expenditure was not attempted. Applying the same formula to exhaustive efforts that reach the upper limits of human capacity, and thus are outside the realm of practical occurrences in industry, seems, however, to place even those extraordinary efforts properly on the new scale, at least by order of magnitude.

In industry measurement of physical effort is not an end in itself. It is a means to an end. If such measurements shall have any practical administrative value at all, the findings must be convertible into the "points" of a Job Evaluation system in use.

We are now dealing with two scales: one is the scale that attempts to measure *units of effort* in a Static-Dynamic-Mechanical sort of a dimension. The other is our Job Evaluation point rating scale which measures in *units of job worth* representing the *value* which we place upon the performance of such effort requirements. To convert

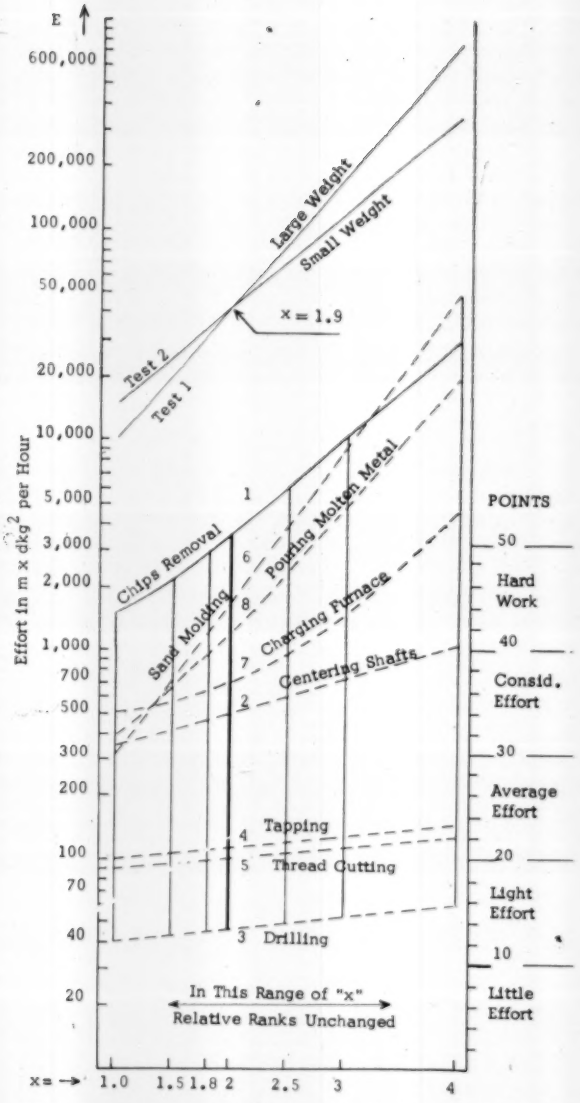

FIG. 14. Experimental Determination of Strain Factor "x" in the Effort Formula: $E = n \times D \times W^x$.

one measure into the other we must know the relationship between the two scales. Empirically, there emerged a logarithmical relationship rather than a linear one.

This is not too surprising, at first, if one considers the exponential character of the relationship between effort and performance itself. The world of sports supplies us with many examples: to reduce the time for running a mile from 4 minutes to 3 minutes and 55 seconds required infinitely *more* effort than reducing it by the same amount of 5 seconds from 5 minutes to 4 minutes and 55 seconds. Ultimately a point will be reached where further time reduction will become impossible because effort would approach infinity; at least for the individual.

The implications of a logarithmical relationship between *units of effort* and *units of job worth* are, at first, somewhat startling but ought to be understood. Apparently, we are assigning less and less *value* to performances that require more and more effort as we go up the scale from light work to hard work. As can be read from Figure 14 we increase the job worth by a value of, say, two points if physical effort increases from 80 to 100 of our new "effort units" but we also increase the value by only two points if effort increases from 800 to 1000 units. Any arithmetical progression of point values in a job evaluation system seems therefore inappropriate at least as far as the factor "physical effort" is concerned. However, there are many systems in use that do just that.

This fact raises some interesting questions about the pay scales of most of our Job Evaluation systems. The *values* which their point scales represent are ultimately converted into a third scale which measures in *units of reward* that we are willing to pay for service received. A vast number of pay scales in use today convert point values in a one-for-one manner into dollars and cents of base pay. Granted, this is no longer *job evaluation* but *wage administration*. However, the question remains: how much sense does it make?

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Labor Incentives—A Failure and a Success

by **JOHN M. COX**

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INCENTIVE systems by their very nature affect the lives of nearly every member of a manufacturing organization. Each person has his own opinion on the values, merits, and desirability of such a pay system. In this paper we discuss two such installations, one successful and one which ended in a strike.

THE SUCCESS

The ABC company is a machining semi-production shop. There are many large machine tools run by men who have gone through an apprenticeship training with the company. About a third of the employees are engaged in assembly type work also involving mechanical knowledge.

Through the war years this company made a sizeable profit and nearly tripled its work force. With this vast amount of inexperienced help, labor standards were relaxed and new standards were based on the performance of these less experienced people.

After, the war business virtually stopped and only long experienced personnel were kept on. Many workers by 1951 were twenty-year men, expert machinists, working on production type jobs. All operators performed their own set ups. However, operator performances were in fabulous ranges. Many workers were taking home pay checks greater than their foremen. Further, great inequality existed between departments.

Even with such performances, an independent union had been defeated by a national union affiliate. This union was, in 1952, in the courts attempting to receive authorization to act as representative of the workers.

SYSTEM

The incentive system introduced to replace the old system was called a standard hour system. It had a one-for-one payment schedule. Time-studied standard data techniques were used. Rates were not set based on a single time study of a particular job but rather time values were established for various functions after accumulating perhaps hundreds of studies on similar equipment. Later, the labor rate or standard was set by observing the functional method, applying times by function, adding the times and coming up with a total time per part machined set up accomplished, or assembly completed.

INSTALLATIONS

As each type of machine was time studied, standard times were developed and the technical part of an installation was ready. At this point, operators in the area, their foreman, a personnel representative and the installing Industrial Engineer met and discussed what the new plan entailed. Operators were instructed on how to make out their own time ticket, how to figure their pay, and shown how performance on one job affected performance on subsequent jobs on a daily basis. It was further pointed out that performance on one day did not affect others. There was no ceiling on earnings.

Installations were made by small groups of up to about 15 people at a time, permitting close follow up by Industrial Engineering and Payroll.

MANAGEMENT'S ATTITUDE

The plan had been "sold" directly to the president of the company so had good support and back-up. Supervision, in general, opposed the tightening of standards in their own areas although agreeing that better standards were certainly necessary elsewhere.

Management together with the independent union promoted a system of time study stewards. These men were trained with the Industrial Engineers on the new time

study technique and were used on grievances involving time standards. After the vote for the international union, after which no union was recognized, the time study stewards were in one or the other union but were accepted by both unions as being their own representatives.

THE APPROACH

Management called in representatives of the then independent union and discussed the labor cost problem, the approach of having time study stewards and the whys of the system. An open book policy was established at this time.

Management promised, and published, material explaining the system in some detail.

LINE ADMINISTRATION

Administration fell in the realm of the foremen who were employee-oriented, having worked as operators themselves, but were also a major part of management. Foremen, generally speaking, supervised cost centers and were responsible for performance in these centers. If performance rose at the same time as "punch out" rose, punch out was questioned by higher levels of management.

A great amount of time was spent selling the line foreman the system. They were frequently brought into discussions on policy and contributed to the continuing efforts to establish such policies.

RESULTS

Some labor unrest existed throughout the installation period of some three years, none to the point of strikes or name calling. Frequent cases of employees trying to beat the system have cropped up but the system is relatively simple and uncluttered making it difficult to cheat.

One serious analytical error occurred, with earnings jumping in one department to 165% versus a plant average of about 125%. This was corrected without serious incident, both workers and the company feeling that things were currently done fairly.

THE FAILURE

The XYZ company is also a machining, semi-production shop. However, runs, while being similar in length to ABC's, are composed of large volumes of smaller parts. Much more punch press work and less heavy machining is done. This company is about three times the size of ABC. The foremen are generally men trained on tool and die work while operators are for the most part semi-skilled workers, many women.

This company also was very profitable during the war years and permitted standards to go out of control, although not nearly so far as did ABC. The policy had been to time study jobs and give the foreman the operator's rate at that time. The foreman approved or revised the rate as he saw fit. Time study men could contest the foreman's decision to the superintendent of the activity involved, but in practice seldom did.

A ten percent cap was placed on operator earnings and since workers reached it so easily, management had no confidence in time standards but accepted the rate of cap as the operator's base rate in effect.

An international union had instituted a vote in about 1950 and another in 1952 but had been soundly defeated. The union used the new incentive plan as the basis for a new attack and the company fought back with mailings and bulletins.

There was a system of representatives set up to deal with workers on an informal basis but the company felt it better to discourage bringing grievances into the open where they might then become major issues.

SYSTEM

The incentive system used to replace the old system had a modified standard hour one-for-one payment schedule based on MTM standard data techniques. Times were established, using MTM, for various functions. These times for functions were then totaled according to the method thought best for each job and a standard set. The method on which the standard was set was included on a Method Instruction Card along with the standard time per piece.

INSTALLATION

As an area became ready for installation, the same procedure as for company ABC was followed in Plant 2, the newer of two XYZ plants, while in Plant 1 authority for worker orientation was turned over to the personnel department. Plant 1's main theme was psychological, the whys of the program due to competitive conditions; Plant 2 spent little time on the whys, concentrating on how to make out time tickets and how to use the Method Instruction Cards (details on the job method).

It was pointed out in both cases that performance on one job did not affect that on others; that each job was guaranteed at base; that there was a weekly cap on earnings of 20 percent.

MANAGEMENT'S ATTITUDE

Outside consultants were used in Marketing and Finance. In Finance, Management was shown a bad labor cost picture, and this was responsible in effect for pushing the incentive program onto Manufacturing Management.

The chief officer of one plant was opposed politically to the Vice President of Manufacturing and appeared to be on the rise whereas the Vice President really had little power. The Vice President of Manufacturing was made responsible for the program and the outside consultant was restricted to dealing with the Vice President's staff.

Foremen generally were indifferent to the program, feeling it not necessary but going along with what they felt was the current feeling of Management.

THE APPROACH

No union representatives were available and representatives from departments in a company committee structure could not legally be treated as employee representatives. The company, therefore, decided on the incentive plan without including workers in the decision.

Instead, employees were given a series of lectures, department by department, explaining the serious competitive situation. Here employees were asked to cooperate and were told that both the company and employees would benefit by the new incentive system. Unfortunately the company's chief executive was voted a substantial salary increase during this period. Union Organizers publicized this fact in pamphlets and on television.

LINE ADMINISTRATION

The main burden of the program fell on the Job Setters who were really merely set up men for about 8 to 24 operators. These men were not part of management but were responsible for authorizing punch out and for supervising set ups made by personnel in their area. These men could see very little advantage to themselves in the system; they were asked to prevent cheating, thus being in the nature of a spy; they were asked to teach their men set ups, thus doing themselves out of a job; they were asked to continue working with the same number of people as before, and since these people were doing some 20 percent more work, to perform 20 percent more set ups with no additional pay advantage to themselves. Generally speaking, Job Setters were 90 percent employee orientated rather than being company minded.

RESULTS

A strike occurred about one and one half years after the program started and Management discarded the new labor standards and cap. At the same time they raised wages to prevent much of a pay reduction for employees making cap earnings under the rejected system.

About one third of the direct employees had been placed on the new incentive system, which appeared to be a fairly successful installation. The department precipitating the strike was composed of women who had worked using the system for two days without knowing how well they were doing.

COMPARISON

1. Both companies had generally loose labor standards due to the influx of war time employees, those of ABC being further out of line than those of XYZ.
2. Both companies had had some labor difficulty and were dedicated to fighting unions, but ABC did have a union through which to deal; XYZ had to resort to letters, bulletins and group meetings for communication with its employees.
3. ABC had no incentive limit for employees; XYZ set a cap of 20 percent. In this connection, XYZ also prevented the publishing of statements that XYZ *would not permit rate cutting* against the advice of their Chief Industrial Engineer.
4. XYZ used MTM times for establishing their data (a good application, I believe) whereas ABC used data developed in their own shop (a good application) by means of time study. The incentive system was given much publicity by the international union trying to organize XYZ. They tried to establish the lack of merit of MTM.
5. ABC had a daily guarantee; XYZ a job guarantee. This encouraged workers at XYZ to punch in and out on jobs such as to be below guarantee on some jobs and way above on others (the 120% cap was based on the week's performance, not that of one job). Thus, low actual performance could be parlayed into cap earnings.
6. XYZ paid for every phase of a job that an operator performed, and each was shown on the time ticket separately. The time ticket became so complex at Plant 1 that the Payroll Department would not permit operators to fill out their own time tickets. This plant added a series of time clerks to do the job. This particular item (figuring incentive earnings) became a bottle-neck in each area at Plant 1 and was particularly prevalent in the area that struck. It took two to three days' work after the strike to find out if the girls had had a reason for striking or not. (It appeared they had, i.e., performance was about 85% average.)

   More work was lumped together at ABC, perhaps introducing a bit less accuracy per job but simplifying things enough so that operators could make out their own time tickets, except where a man was unable to write English.
7. ABC's presentation before an installation was an exchange of technical information among people working together. This applies to Plant 2 of XYZ also but not to Plant 1 of XYZ where the installation presentation was made by people who knew neither the workers nor the technical details of the job.
8. The XYZ Company was more beset by politics and the incentive system was the responsibility of the political loser, his entire function being in the process of being gradually reduced prior to the installation of the new plan.

   He was given responsibility for the incentive system but was given no added authority to install it. ABC's plan was the responsibility of the President, problems of a major nature going directly to his office for review and control.
9. Workers at ABC had their own representative to verify standards in the way of time study stewards. No one was available to represent workers at XYZ, when they were dissatisfied with a labor standard.
10. XYZ gave the worker no guarantee that rates once established would not be cut except for good reason. Both worker and Management had a history of seeing bad rates and Management was not going to let a bad rate continue.

    ABC realized that a bad rate would have had to be the result of some correctible error, so made a "no rate cutting" guarantee in writing as part of a contract with the independent union. This was also included in literature given to employees on the techniques used in establishing labor standards.
11. Labor unrest existed in both companies before the new incentive plans were installed and continued on afterward. To outward appearances, such unrest appeared worse at ABC. (The independent union had lost an election.) Unrest was certainly more obvious, and grievances were sometimes introduced purely to harass management or the competing union. The labor case in court was the cause for much agitation.
12. Those in a direct line capacity doing the first line administration job were more a part of Management at ABC than at XYZ.

CONCLUSIONS

One system has become a success and may be pointed to as an example of a good installation, that of the ABC company. Some of the same individuals involved in the ABC installation moved on to XYZ and helped install a failure. Why?

Obviously the problem was not a technical one—one of the quality of the labor standards. If anything, the system at XYZ was more precise, accurate and provable than the one at ABC. But there was no labor representative to look! There was no one who could be convinced by facts! No one was trained to understand the facts even if they were to look at them!

It would seem reasonable to say that:

1. Companies need to update their labor standards continually if they hope to keep them in line.
2. Having a union through which to deal is a good method of communicating with workers; better than letters and bulletin boards.
3. An incentive cap indicates lack of confidence on the part of management in the basic quality of labor standards.
4. MTM and Time Study are both workable from a technical standpoint.
5. A daily guarantee doesn't encourage cheating as much as a job guarantee.
6. A time ticket that an operator can make out is easier for him to understand than is one that must be made out by a special time clerk.
7. It is important that operators understand all the technical information necessary to an incentive plan if they are to support the plan.
8. Politics in a company contribute to the probability of an incentive system's failure.
9. Operators trust their own representatives more than they trust Management people.
10. Operators like to know that rates will not be tightened just because an operator performs well on a particular job.
11. Apparent unstability of labor conditions is not necessarily proportional to the probability of success or failure of an incentive system.
12. Line supervisors need to be in accord with the incentive plan and must be qualified to handle the administrative job for which they are held responsible.

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Construction of Linear Programming Model

by **PAUL H. RANDOLPH**

Associate Professor of Industrial Engineering, Purdue University

LINEAR programming has assumed a position of major importance in recent years. More and more applications of the technique are being found daily. Colleges and universities are making it a regular part of their curriculum.

One reason for the importance of this tool is that it is a method for studying the behavior of a large number of systems. It is probably the simplest model that can be constructed for broad programming problems of industry and government. Yet in spite of this simplicity a surprisingly wide range of applications have been found for linear programming.

Unfortunately, the major emphasis in the teaching of linear programming has been on the techniques of finding the solution to systems of linear equations. Thus, considerable emphasis has been placed on the simplex method, the transportation method, the assignment method, and so on. While methods of solution may be the central mathematical problem of linear programming, they do not make up its definition. In fact, with the wide variety of computer programs that are now available, the method of finding solutions fades into secondary importance to the problem of formulating the model for the average practitioner.

It is the purpose of this paper to present a fairly well structured method for constructing linear models. If the procedures given here are followed, the formulation of the model becomes less of an art and more of a science. This presentation will be made through examples which are obviously fictitious. This is done to keep the development of the principles on a level that can be easily followed. Once the fundamentals of the procedure become apparent, it will be found that the models for large and complicated problems can be constructed quite readily.

In passing, it should be pointed out that the ideas of this paper follow quite closely the presentation of George Dantzig (1) which will soon be available as a part of his book (2).

MACHINE SCHEDULING PROBLEM

To illustrate, let us begin with a simple example which is probably familiar to most readers. Suppose a company manufactures two types of screws: Type I and Type II. The manager has only one week of 40 hours for producing these screws. Since the plant works at 90% efficiency, he assumes he has only 36 productive hours available. Each screw requires processing on two machines: an Automatic Screw Machine and a Slotter. The time required for each type (in hours) is

	Screw Machine	*Slotter*
Type I	.05	.02
Type II	.02	.03

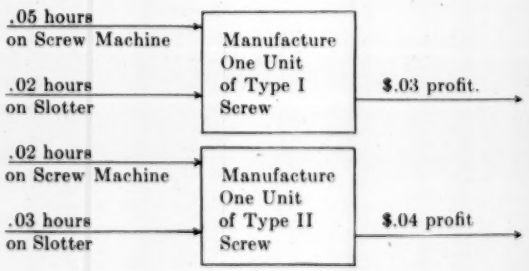
The profit for each type is

Type I	$.03
Type II	$.04

Let us assume that he has sufficient raw material, labor and other items to manufacture as much of each type as he needs. Thus, the only restriction is the 36 hour productive week. The problem is: How many of each type should he produce in order that the greatest profit might be realized?

The first step is to consider the entire system as being decomposable into a number of elementary functions called "activities." In our problem we can define two activities: 1. manufacturing one unit of screw type I, and 2. manufacturing one unit of screw type II.

Next, each type of activity can be abstracted to be a "black box," into which flow tangible items, such as supply and money, and out of which flow the results of this activity, such as products of manufacture. In our problem we can define the inputs as time required for each unit on the automatic screw machine and time required for each unit on the slotter. As a result of each activity the company realizes a profit for each screw type. Thus the black boxes of the activities with the flows can be represented as follows:


.05 hours on Screw Machine
.02 hours on Slotter
Manufacture One Unit of Type I Screw
$.03 profit.
.02 hours on Screw Machine
.03 hours on Slotter
Manufacture One Unit of Type II Screw
$.04 profit

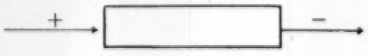
Now the problem is to determine the quantity of each type of screw that should be manufactured such that the profit is a maximum. That is, we want to find the amount of each unit activity. This quantity is called the level of the activity. The activity level can be varied by varying

the flows into and out of the activity. In *linear* programming the quantities of flow of each item into and out of the activity is always proportional to the activity level. This means that only the flows for the *unit* activity level need to be known. If the activity level is to be doubled, then all flows to and from the unit activity level are to be doubled.

Suppose we use the rather common notation of x_i to measure the level of the i th activity. Thus, in our problem we can use x_1 and x_2 to measure the activity level of Type I and Type II, respectively. That is, x_1 denotes the quantity of Type I to be produced, and x_2 the quantity of Type II. It should be pointed out that these activity levels cannot be negative. It would seem strange that one could reach the conclusion that -25 parts are to be produced. The implication would be that 25 items of finished stock is run backwards through the machines until they become raw material. Thus we will insist that negative quantities are not admissible.

We can now establish a restriction for the total flow of each item into or out of the activities. For example, there is a total of 36 hours available on the automatic screw machine. Thus, we want to choose levels of the two manufacturing activities so that we do not exceed the 36 hours on this machine. The total number of hours on the automatic screw machine required by Type I is $.05\ x_1$ and by Type II is $.02\ x_2$ where x_1 and x_2 are the activity levels for types I and II respectively. Thus, the total hours on or the total input to the automatic screw machine will be $.05\ x_1 + .02\ x_2$ and this total must not exceed 36 hours. That is, $.05\ x_1 + .02\ x_2 \leq 36$. In like manner we can state that the restriction for the slotter is $.02\ x_1 + .03\ x_2 \leq 36$.

In the above inequalities the signs of the inputs were all positive. To distinguish inputs from outputs, the sign convention in this paper will be plus $(+)$ for input and minus $(-)$ for output.



The value of this will be apparent shortly.

The objective of all linear programming problems is to optimize an item of utility, usually monetary in nature. Some activities require money and other activities produce money. By using the sign convention of the preceding paragraph, activities that require money contribute positively and those that produce money contribute negatively to the total cost. Thus, the item of cost can be represented as a single function, which is to be minimized.

In our problem only outputs of money are noted. Therefore, the total cost is $-.03\ x_1 - .04\ x_2 = z$. Note that following the convention of Dantzig (1) this total cost is called z.

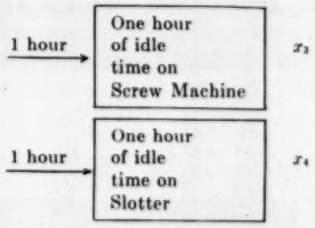
Thus, we have built up a system of two linear inequalities and a cost function. This enables us to restate our problem as follows: To find non-negative values of x_1 and x_2 which satisfy

$$.05\ x_1 + .02\ x_2 \leq 36$$
$$.02\ x_1 + .03\ x_2 \leq 36$$

and which minimize

$$-.03\ x_1 - .04\ x_2 = z$$

Finally, it is desirable (especially to facilitate algebraic methods of solution) to consider a slightly different form for the system. Instead of an incomplete accounting of the total resource of each item as expressed by the inequalities, it is desirable that the system of activities be *complete* in the sense that a complete accounting of the activities can be made for each item. That is, the total of the inputs minus the outputs should balance with the amount available. Usually this implies the detailing of additional activities, generally called "slack" activities. In our problem we can represent a unit idle time activity for each machine as follows:



If we donate the level of these slack activities by x_3 and x_4, respectively, then it is apparent that we can account for all 36 hours on each machine, getting the restraint equations

$$.05\ x_1 + .02\ x_2 + x_3 = 36$$
$$.02\ x_1 + .03\ x_2 + x_4 = 36$$

and the cost function

$$-.03\ x_1 - .04\ x_2 = z$$

Thus, there is a complete accounting of each item, yielding a system of "material balance equations." As Dantzig (1) states it,

> The *programming problem* is to determine values for the activity levels which are positive or zero such that flows of each item (for these activity levels) satisfy the material balance equations and such that the value of the cost is a minimum. It is clear that the programming problem has been reduced to a well-defined mathematical expression called the LINEAR PROGRAMMING MODEL.

A TRANSPORTATION EXAMPLE

A tractor manufacturer has three warehouses that have tractors on hand and two contractors that require more tractors in their fleet. The quantities on hand or required are given by:

Warehouse	Cases on Hand	Contractor	Tractors Required
I	10	A	25
II	20	B	30
III	40		

The cost of delivering each tractor from the warehouses to the contractors is given in the following table:

(To) \ (From)	I	II	III
A	24	21	37
B	8	16	17

The objective of the company of course is to determine a shipping schedule which minimizes the total cost of transporting the tractors from warehouses to customers.

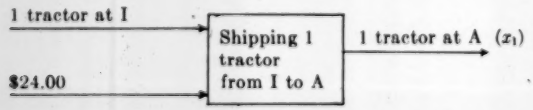
To set up the model which describes the shipping of tractors from warehouses to contractors it might be felt that only one kind of item is available—namely, a shipment of tractors. However, economists point out that *the same item at different locations or at different times are essentially different items.* For our present purposes we can ignore the time dimension and concentrate only on the different locations. Accordingly, our list of items are:

1. Tractors at I
2. Tractors at II
3. Tractors at III
4. Tractors at A
5. Tractors at B
6. Expenditures (Dollars)

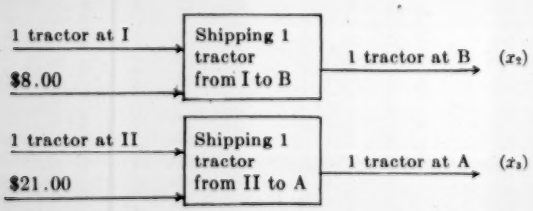
In addition there are six different types of unit shipping activities that may possibly be used:

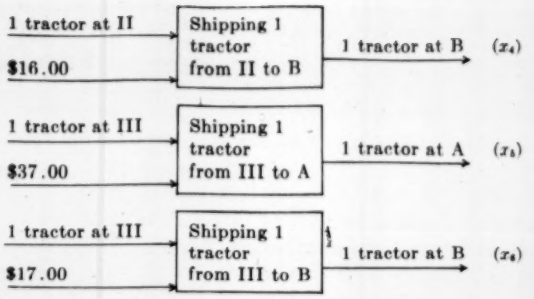
1. Shipping a tractor from I to A
2. Shipping a tractor from I to B
3. Shipping a tractor from II to A
4. Shipping a tractor from II to B
5. Shipping a tractor fom III to A
6. Shipping a tractor from III to B

Let us now abstract our shipping activity as a "black box." For example, in the activity of shipping one tractor from Warehouse I to customer A the inputs to this activity are one tractor at I and \$24.00; the only output is a tractor at A. This can be represented as



Similarly, remaining transportation activities can be abstracted as follows:





Now let us denote the number of tractors to be shipped from warehouse I to customer A by x_1. In like manner the levels of the remaining shipping activities can be measured by x_2, x_3, x_4, x_5, and x_6.

To construct the material balance equations, let us consider the last item first. Since a total of twenty-four dollars is required for each tractor in activity one, the contribution of this activity to the total shipping cost can be denoted by $24x_1$. Similarly, the contributions of the remaining activities are $8x_2$, $21x_3$, $16x_4$, $37x_5$, and $17x_6$, respectively. Thus, the total shipping cost can be represented by the following material balance equation:

$$24x_1 + 8x_2 + 21x_3 + 16x_4 + 37x_5 + 17x_6 = z$$

Our object is to find a shipping schedule which will minimize this function.

The remaining five items can be represented in algebraic form in similar manner. Since the total quantity of tractors at the warehouses exceeds the demand by the customers, it is evident that the shipping activities will provide a complete accounting for items 4 and 5 but not for items 1, 2, and 3. That is, the shipping activities *may* account for less than 10 tractors at warehouse I. To represent this we can say that the total of the shipping activities for item, that is, x_1, x_2, is less than 10; or

$$x_1 + x_2 \leq 10$$

Likewise, for items 2 and 3 we have

$$x_3 + x_4 \leq 20$$
$$x_5 + x_6 \leq 40$$

In all of these inequalities the coefficients for each activity are positive since the unit quantity for each activity level is an input.

Items 4 and 5 are outputs and thus require a negative sign. Since the quantity is one per activity level, we can write:

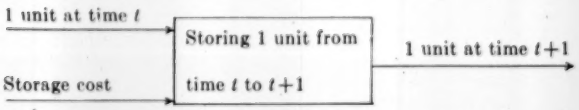
$$-x_1 - x_3 - x_5 = -25$$
$$-x_2 - x_4 - x_6 = -30$$

As before, it is desirable to express the restrictions as material balance equations rather than inequalities. By considering the three activities of storage at each warehouse in addition to the six shipping activities, then a total of nine activities can be distinguished.

1. Shipping from I to A
2. Shipping from I to B
3. Shipping from II to A
4. Shipping from II to B
5. Shipping from III to A
6. Shipping from III to B
7. Storing excess at I
8. Storing excess at II
9. Storing excess at III

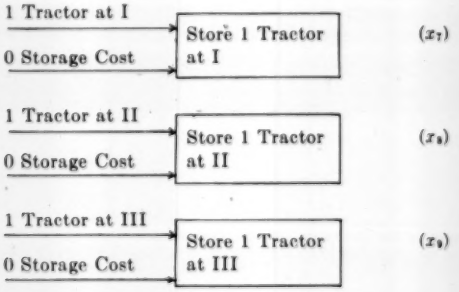
In general, the additional activities are called slack activities.

Usually storage activity implies an item flows into the activity at some time t and flows out at some later time, say $t + 1$. Normally there is some cost attached to it. Thus the typical abstraction of the general storage activity is



The similarity of this with the shipping activities occurs because the shipping activity is a transfer in space while storage is a transfer in time.

Since in our particular problem we are not considering the outputs at later times our storage activities take the following simplified form.



Since activities 7, 8, and 9 require no costs, they contribute nothing to the total shipping cost and thus will not alter the cost function. However, these activities do contribute to the total amount of item 1. Thus, the first material balance equation reads

$$x_1 + x_2 + x_7 = 10$$

where x_7 is the amount stored at warehouse I. This equation states that the 10 tractors available at warehouse I are *completely accounted* for by the number of tractors shipped from warehouse I to the two customers $(x_1 + x_2)$, plus amount stored at I, (x_7). This is also true for the other two items.

Thus, the complete system of equations becomes:

$$\begin{aligned}
x_1 + x_2 \qquad\qquad + x_7 \qquad\qquad &= 10 \\
x_3 + x_4 \qquad\qquad + x_8 \qquad\qquad &= 20 \\
x_5 + x_6 \qquad\qquad + x_9 &= 40 \\
-x_1 \qquad -x_3 \qquad -x_5 \qquad\qquad &= -25 \\
-x_2 \qquad -x_4 \qquad -x_6 \qquad\qquad &= -30
\end{aligned}$$

with the cost function

$$24x_1 + 8x_2 + 21x_3 + 16x_4 + 37x_5 + 17x_6 = z \ (= \text{Total Costs})$$

The mathematical problem is to choose that program of activity levels, i.e., $x_1, x_2, \ldots x_8$, and the total costs, z, such that all x's are positive or zero, the material balance equations are satisfied, and z is minimized.

CONCLUSIONS

By careful applications of the methods described in this paper, all problems of linear programming can be accurately translated from a verbal description to a mathematical model ready for solution. Techniques for solving such systems constitute the central mathematical problem of linear programming, and can be found in detail in Dantzig's forthcoming basic text (2), or in other books on linear programming.

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(1) Dantzig, G. B. "Formulating a Linear Programming Model," Rand Report P-893 (1956).

(2) Dantzig, G. B. *Linear Programming.* (Forthcoming.)

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The Engineering Community and the Industrial Engineer

by **WILLIAM J. JAFFE**

Professor in Management Engineering, Newark College of Engineering

NOT too long ago, a novel appeared, which, by its title, brought into deserved prominence the writings of an author who had lived three hundred years ago. Expressing some thoughts which have seldom been equalled in literature, John Donne wrote:

> No man is an ILAND, intire of itselfe; every man is a peece of the CONTINENT, a part of the MAINE; if a CLOD be washed away by the SEA, EUROPE is the lesse, as well as if a PROMONTORIE were, as well as if a MANNOR of thy FRIENDS or of THINE OWNE were; any mans DEATH diminishes ME, because I am involved in MANKINDE; And therefore never sent to know for whom the BELL tolls; It tolls for THEE.

Even though the true significance of the concepts expressed is still far from universal realization, man has, for a goodly number of years, joined in cooperative efforts and enjoyed the society of his fellows. Certainly the motives that brought early man together were probably much more primitive, much more basic, and much more physical than those that have resulted in, say, the suburban developments of his descendents. But they were no more realistic than those that are current.

This need for association, this desire for the exchange of information, this compulsion towards a unified advancement of mutual interests is even more strongly felt among those whose common intellectual interests would wither away without this free intercourse. Clearly, no body of knowledge or practice can exist in a vacuum. If, Newton, despite his genius, remarked that he "saw far" because he "stood on the shoulders of giants," the debt of those who followed him would be infinitely greater.

Moreover, it is not easy to draw a boundary around a body of knowledge or practice and to adopt a policy of isolation. One does not have the right to prevent a free flow of ideas to others who can benefit from them; moreover, he has an obligation to aid in their free interchange. Although the hoarder is frequently depicted in both legend and newspaper stories as spending his time in opening his storebox in private, counting and recounting its contents, and replacing the box in its secret hiding place, the possessor of ideas cannot engage in this solitary practice. But probably most important to the true *professional*, one of the most basic and fundamental of all requirements for the existence of a *profession* is that there be a free interplay of ideas and a liberal association of those persons who lay claim to them.

GROUP ORGANIZATION

Full professional activity cannot be achieved within individual confines. It can only thrive in the company of fellow practitioners. In addition, there must not only be a group of persons formulating, expanding, and guarding a body of knowledge and art, but there must be an organization of the group. Among the more important of the many duties of this organization are the definition of the body of knowledge and practice, the educational activities connected with its establishment and promulgation, and the establishment of standards—both as to personal qualifications for entrance and a code of conduct for maintenance of membership.

The attempts of the engineers to formulate such professional organizations came, when compared to the traditional professions of divinity, medicine, and law, more or less recently. In the United States, for example, the American Society of Civil Engineers (ASCE), the oldest of our professional engineering societies, only six years ago celebrated its centennial. The American Institute of Mining—it added "Metallurgical" to its title in 1919, and only recently the additional connotation of "Petroleum"—Engineers was founded in 1871, and the break-away from "Civil" (or really non-military) engineering began, The American Society of Mechanical Engineers (ASME) dates from 1870, the American Institute of Electrical Enginers (AIEE) from 1884, and the American Institute of Chemical Engineers (AIChE) from 1908. As for the AIIE, it has now reached the age of 10.

The history of all these societies is most interesting, and much concerning the needs for such associations can be gleaned from even the most cursory examination of their formation. Thus, ASME's beginnings go back to the days when the *American Machinist* was being published in a tiny office, 96 Fulton Street, in downtown New York. ASME's (1882) President J. E. Sweet has presented, in the *Transactions of 1910*, a very vivid picture of the Society's founding and the attempt "to foster closer relationships between the publishers and the contributors" as well as "the notion that it might lead to an organization." Again, the late H. S. Person used to

recount the fact that "the group of young engineers associated with Mr. Taylor" had found difficulties in getting all their papers presented before existing societies. The result was that, with Frank Gilbreth as host, a group of "scientific management" pioneers—M. L. Cooke, R. Kent, C. Lauer, and W. Lewis—met at the New York Athletic Club and, in 1910, the Taylor Society (the Society to Promote the Science of Management) was born. As for the AIIE, Wyllis G. Stanton still recites a most fascinating story about its foundation and the need for its organization.

Clearly, then, this need for association has been the *sine qua non* of the movement toward a profession. However, such an association is not limited to individuals forming a society but has extended also to societies forming a unified organization. For, after all, as each group of persons with detailed interests broke away from the nonmilitary engineering group in order to cultivate more intensely its own interests, many problems common to all sprang from this common heritage. Just as in other professions, for example, the Presbyterian minister still considers himself as a member of the greater body of clergymen, the cardiologist still identifies himself with the medical profession, the mechanical engineer or the Industrial Engineer or the electrical engineer must still consider himself—and, even if he does not, the public does—*an engineer*. This association makes an exchange of ideas much easier, and it is quite natural that such a unified concept must exist.

It is doubtful if there can be any clearer exposition of the relation of the Industrial Engineer, in particular, to the engineering profession than that expressed by AIIE's President George H. Gustat. As rich as the *Journal of Industrial Engineering* of September-October, 1958, was in the presentation of the Proceedings of the Ninth Annual Conference at Los Angeles, the pages devoted to the President's Message were among the most important. These pages should be read and reread, and the ideas expressed are repeated here in a highly abbreviated form:

> There are some who think we should work independently—that as Industrial Engineers we do not have that much in common with other engineers. I would like to remind this group of just some of the things that we share in common with other engineers that in themselves make continued coordination and unity of purpose a desirable pattern of behavior:
>
> 1. We have a common heritage . . .
> 2. All engineering has its roots in the pure sciences and abstract thought . . .
>
> The general aim for engineering educators is the same for all branches of engineering—the accumulation, testing and application of scientific data. It is not at all uncommon today for an engineering graduate to have been exposed to courses in fields of engineering other than his own. In fact, many go on to successful careers in fields other than the one in which they received their degree. In many other instances engineers in different fields of specialization work closely together as a team. This pattern of cooperation marks the engineering profession as a whole.
>
> 3. We share a common definition . . .
> 4. The professional engineering societies . . . currently . . . have either accepted in substance or are approaching the standards proposed by the committee on Professional Recognition of the Engineers Council for Professional Development . . .
> 5. A number of other items can be grouped as areas of common interest to all engineers: a. The continual education of engineers . . . b. The question of professional status . . .
> 6. Every engineer regardless of his field of specialization is a representative of the engineering profession in the eyes of the general public. What each of us does and says as an individual reflects on the engineering profession as a whole.
>
> We have an inherent interest, therefore, in just about everything that affects the engineering profession. . . .

As further evidence of AIIE's implementation at the national level of this common interest, President Gustat emphasizes the Institute's membership in the Engineers Joint Council and its participation on the Nuclear Congress Committee, the Committee on International Relations, the Manpower Commission, the Practice of Engineering Committee, the Program Committee, and EJC's Board of Directors. He also looks with justified anticipation to AIIE's work on the National Engineers Register and the following committees: Secretaries, Editors, Finance, Membership, Planning, Employment Conditions, Recognition of Specialties, Engineering Services, Who's Who in Engineering, and Insigne. And, lastly, he points to the invitation by the Founder Societies for AIIE to joint sponsorship of future Engineering Management Conferences and to participate with ECPD in the accreditation of Industrial Engineering College Curricula and the Professional Development of the Young Graduate.

President Gustat's remarks represent an enlightened view, but universal acceptance came many years after the early engineering leaders considered the advantages of such adhesive forces. To the early advocates, union was a pure bread-and-butter affair, and one would not be amiss in suggesting that economic advantages of a unified profession were as—if not more—important than the intellectual ones.

NEED FOR ENGINEERING CENTER

As early as 1887, just three years after its founding, the members of AIEE felt the need for a home for its Institute in a building where all of the engineering societies might be housed. Yet, the AIEE's early recognition of the wastefulness and inefficiency of maintaining separate addresses was not limited to such things as a common mailing address, but it extended to a great number of items that required a goodly sum of money to duplicate merely for the sake of duplication. This building—or better, community—of engineering societies could provide, at a minimum cost, such important items as a common auditorium, a common library, a common front, and the numerous other needs that not only could—but should—be enjoyed together.

The early efforts of the AIEE leaders did not bear fruit immediately. After all, the societies were still in the splintering process, and the fact that there were areas for splicing was contrary to their thinking at the time. However, it did not take long for the engineering leaders to perceive the folly of each society going its full way alone. And, as the 19th Century drew to a close, many engineers, particularly those of national prominence, were fully cognizant of the benefits to be gained by cooperation. After all, even in 1878, the ASCE, AIME, ASME, and AIEE had a combined membership of 3,600. (This is about one-half of what AIIE, a relative newcomer, has by itself at present!)

The first real attempt at unification came in 1895, when W. D. Weaver of AIEE presented, to Andrew Carnegie, a plan for a combined building: Mr. Carnegie expressed interest, but no action came at that time. The next move was, to say the least, a most interesting one. It came six years later, and it followed an occurrence in London which indirectly had a great impact on the development of the American engineering societies. The Latimer Clark Library, which was probably "the second most important electrical and scientific library in the world," was, because of the death of its owner, up for sale. Mr. Weaver persuaded S. S. Wheeler, another member of AIEE, to buy it. Dr. Wheeler did this, but he presented it to the AIEE on the condition that a suitable building be provided within five years to house this important collection.

The next step was an obvious one. For, although Mr. Carnegie was well known as an industrialist, he was becoming even better known, in even the smallest hamlet of the country, for his great interest in libraries. Consequently, AIEE President C. Hering, accompanied by J. W. Lieb and G. Dunn, called on Mr. Carnegie who immediately donated $8,000 for bookcases and cataloging and invited this committee to keep him informed of its plans.

PLANS FOR ENGINEERING CENTER

With this action as a catalyst, the idea of a common home for all the engineering societies continued to be a topic of interest at all engineering society functions. Thus, for example, in 1902, at the 25th Anniversary Meeting of the Engineers' Club of Philadelphia, C. F. Scott called for cooperation among engineers in the task of establishing a common home. On February 9, 1903, as president of AIEE, Dr. Scott was host at a dinner in New York. Here, in the presence of Mr. Carnegie as an invited guest, the message presented in Philadelphia was repeated. The very next day, Dr. Scott, together with Calvin Rice, vice president of AIEE—he was a friend of the Carnegies, and he later became ASME's secretary—called on Mr. Carnegie, by invitation, to discuss the "union engineering building." The next day, eleven unofficial representatives of ASCE, AIME, ASME, AIEE, and the Engineers' Club (of New York) met at the club's headquarters at 374 Fifth Avenue, and this group agreed that cooperation among the societies was feasible. As an example of previous cooperative action, attention was called to the establishment, in 1902, of the John Fritz Medal, which was awarded annually "for notable scientific or industrial achievement" and recognized as "the highest honor bestowed by the profession in the United States." Six members of this group then conferred with Mr. Carnegie who, in a letter addressed to the four national engineering societies and the Club, offered $1,000,000 for a building and for the establishment of a national engineering library.

Three societies promptly accepted, but ASCE failed to join. The Civil Engineers had built their own building in 1897, and they decided against abandoning their six-year-old building on 23rd Street to go along with the other engineering societies at that time.

Although Mr. Carnegie was disappointed in this break in the consolidated action, he, nevertheless, on March 14, 1904, wrote a letter to the others which has since taken on some measure of historical significance. Concise but important as a milestone in the development of the engineering profession in the United States, it read:

Gentlemen of The Mechanical Engineers
Institute of Mining Engineers
Institute of Electrical Engineers
Engineers' Club of New York:

It will give me great pleasure to devote, say, one and a half million dollars for the erection of a suitable union home for you all in New York City.

With best wishes,

Very truly yours,

Andrew Carnegie

Four days later, the Joint Committee officially became "The Engineering Building Committee," which, in turn, divided itself further into two groups—one for the Engineering Societies' Building, which obtained $1,050,000 or 70% of the gift, and the other for the Club, which obtained $450,000 or 30% of the original grant.

UNITED ENGINEERING SOCIETY

Because the Mining Engineers were unincorporated, the AIME could not participate in the ownership and occupancy of the property on the same basis as the other organizations. Hence, a joint holding or trustee corporation was necessary, and the Committee succeeded in having drafted and introduced into the New York State Legislature a bill creating a body corporate, known as the "United Engineering Society," to conduct the trust created by the gift, to administer the desired building, and, in other ways. "to advance the engineering arts and sciences." On May 11, 1904, Gov. Benjamin B. Odell signed the bill into law.

On December 16, 1904, the United Engineering Society (UES) held its first meeting at the ASME Headquarters at 12 West 31st Street, New York, and it began conduct-

ing its business from here as its temporary office. Each of the participating societies received a "Founder's Certificate," recalling the fact that "Andrew Carnegie, in the year 1904, created a trust for the engineering profession of America, by giving one and a half million dollars for the erection of buildings to be used for the advancement of the engineering arts and sciences, and all their branches, and for the maintenance of a free public engineering library."

The actual site, purchased by contributions from industry and from "members and friends" of the engineering societies, was situated on the north side of West 39th Street—numbers 25 to 33—between Sixth and Fifth Avenues in New York. It represented land with a frontage of 125 feet and a depth of 98 feet 9 inches. The lots were purchased through the UES in December, 1904, for $541,380.18 from Robert A. Franks, who, acting as Mr. Carnegie's agent, had assembled the property. (During the previous spring and summer, the old residences on the land had been removed.) Number 23 West 39th Street was purchased for $100,000, but it was sold for the same amount to the Engineers' Club, with limitation as to the height of any building that might be erected.

UES CENTER

The proposed Engineering Societies Building created a good deal of attention—particularly because of the unique purposes of the building. Since its architecture and design were to be chosen by competition, by June, 1904, as many as twenty-six sets of drawings were submitted. With Professor W. R. Ware of the Department of Architecture of Columbia University acting as the Committee's adviser, the design submitted by R. D. Hale (later of the firm of Hale and Rogers) and his associate, H. G. Morse, was chosen. In July, 1905, a contract with Wells Brothers and Company of New York for the construction of the building was authorized. On May 8, 1906, Mrs. Carnegie laid the cornerstone; on November 22, the UES met for the first time in the building; by December 1 the building was completed; and by the 15th of that same month the UES assumed management.

At its completion, the building had thirteen stories, a basement, a sub-basement, a reading room, stockrooms for library purposes, and space for several societies.

The dedication ceremonies extended over five days—April 15 to 20, 1907. Greetings came from the President of the United States, the Governor General of Canada, the President of Mexico, and numerous American and foreign societies and institutions of learning. Alexander Graham Bell was the recipient of the combined societies John Fritz Medal for "the invention and introduction of the telephone." Each of the secretaries of the three participating societies received a gold medal for services covering at least a quarter of a century. Between the 15th and the 18th, many technical papers were presented. The functions on the 16th and 17th were highlighted by addresses by Mr. Carnegie, the presidents of AIME, ASME, AIEE, and the Engineers' Club—as well as one by Yale University President A. T. Hadley, which dealt with The Professional Ideals of the Twentieth Century. In addition, on the 19th, there was a vaudeville presentation at the old Madison Square Garden Concert Hall. On the 20th, numerous visits were arranged to the several tunnels then under construction in the City of New York. A general reception took place in the Auditorium on the evening of the 16th, which was followed by receptions in various quarters of the respective societies.

On April 17, along with the more serious news of the day—plus, of course, such lighter reports of happenings in New York as a performance by Anna Held, an announcement of the prospective opening of "Little Johnny Jones" with George M. Cohan, and a victory of the (then New York) Giants over the (then Brooklyn) Dodgers—*The New York Times* story of the Engineering Societies Building's dedication featured the words of Dr. Scott:

> Mr. Carnegie, it has been your great privilege to make this possible. It has been transformed into bricks and mortar. But your letter gives more than money; it is an ideal: "a union home for you all." That, too, has transforming power. Already the harmonizing feature was an actual force. Our societies are working together. They are getting a broader view of their position and a new inspiration for the large work that lies before them.

Not only did this association of engineering societies continue to prosper and serve the needs of the growing engineering profession, but the advantages of this "union" were becoming more and more apparent. As a matter of fact, so successful had this combined venture become that the ASCE—the oldest of the American engineering societies, the society that had originally decided against joining the others, the society that had planned to "go it alone" and not abandon its own building—soon began to look with favor on closer physical association. By 1916, negotiations for ASCE's "return to the fold" were in full swing, and by mid-summer (August 10), it became a member of the United Engineering Society and its fourth "Founder Society."

ADDITION TO UES CENTER

In order to accommodate the Civil Engineers, three additional stories were added to the Engineering Societies Building. This was not an easy matter, because the original building had not been designed for such expansion, and some unusual construction was found necessary: "inside the building, openings were made and four columns were set, from bed rock to the roof, on which the additional three floors were constructed, making actually a building on stilts, over and actually not a part of the old building." The cost of this addition, designed by one of the original architects, Mr. Morse, was about $300,000—the original building and land had cost approximately $1,700,000, of which Mr. Carnegie had given $1,050,000.

So that the four societies could be equal partners, the

ASCE provided $262,500, while the other three, AIME, ASME, AIEE, gave $12,500 each of the required $300,000. And so, the attempt of a large and important engineering society at "going it alone" came to an end. And, on December 17, 1917, the Civil Engineers were officially and warmly welcomed to the Engineering Societies Building.

UES LIBRARY

One of the most potent of the services offered by the combined Engineering Societies building was, of course, the Library. It should be remembered that AIEE brought with it the Latimer Clark Library—a collection that was surpassed only by that of the British Museum. It is interesting to note that, for a time, the libraries of each of the participating societies were maintained separately in the "new" building. But, on April 4, 1907, a Library Committee, consisting of one member from each society was formed. In 1908, Miss L. E. Howard became chief librarian, and she was succeeded, in 1910, by W. P. Cutter, who served until 1917. However, by amendment of the by-laws, in 1912, a "Library Board" took over the management of the Library, and a public engineering library was the result. In 1915, an agreement was made for a joint library to be known as the Engineering Societies Library, and, in the following year, the space was enlarged and the ASCE's library was integrated with the others. The societies' libraries were thus all combined and recataloged as one collection under agreements ratified in 1915, in 1916, and as recently as 1951.

To many individuals, engineering firms, and industrial concerns—not only in the New York area but throughout the country—the existence of a combined library service would have been sufficient grounds for the "union." For, not only is there assembled in one place so great a collection of engineering books, periodicals, and reports capable of so extensive a circulation, throughout the country, both in original and reproduction form, but it facilitates and, consequently, encourages the giving of sizeable gifts for its maintenance and continued enlargement. Thus, as early as 1916, Dr. J. Douglas of AIME, gave $100,000 as the beginning of an endowment to be used exclusively for the Library. This was followed by many more additions by E. D. Adams, J. H. McGraw, W. S. Barstow, to mention but a very few.

It is interesting to note historically that the first Librarian, H. W. Craver, who came from the Carnegie Library in Pittsburgh, served until 1946, when he became a consulting librarian, a post which he held until his death in 1951. His successor, the present incumbent, R. H. Phelps, was formerly with the National Academy of Sciences Research Council.

Another interesting function of the Engineering Societies Building concerns the fact that it essentially serves as a Hall of Fame for the engineering profession. It is a repository for many memorials—bronze busts, tablets, portraits, and mementoes of distinguished national leaders and eminent engineers. Beginning in 1906 with a bronze bust of Carnegie and tablets commemorating his gifts as well as those of members and friends, there are such memorials as a plaque for Dr. Wheeler who acquired the Latimer Clark Library; a portrait of A. Swasey in tribute to him as a founder of the Engineering Foundation; a tablet honoring Albert Noble for his work on the Panama Canal, the Sault Ste. Marie Locks, the Pennsylvania Railroad Tunnels under the rivers in New York, and the Catskill Aqueduct; a portrait of J. Douglas for his gift which began an endowment for the Library; medallions honoring General Pershing and Marshal Foch; a replica in miniature of the statue of J. F. Stevens, set up in Maria Pass through the Rocky Mountains, for his work in discovering this important route to the Pacific; a tablet to H. V. Winchell for his contributions to mining geology; the bronze memorial to Admiral Stevens; the oil paintings of H. D. Adams, H. Hoover, and many others; and the flags of the various Regiments of Engineers. These are but a very few of the testimonials to the profession and its leaders.

ENGINEERING FOUNDATION

To return to the story of the further development of the association of engineering societies, mention must be made of a report which was made in 1914 by UES President Gano Dunn. Even then the strength of the "union" of engineering societies had been such that a number of grants were made, and the Dunn Report was concerned with a substantial gift by a "prominent engineer" who had expressed a willingness to present a considerable sum of money for the advancement of the engineering profession. Hence, to study the means by which this gift could be accepted, the UES appointed a committee. As a result, the Engineering Foundation was established with the very lofty aim of the "furtherance of research in science and engineering, and the advancement in any other manner of the profession of engineering and the good of mankind." UES was made custodian of the capital, the income from which was to be applied by the Board to the Engineering Foundation. The Foundation was officially inaugurated in 1915 at ceremonies at which many engineering notables—President H. S. Pritchett of the Carnegie Foundation for the Advancement of Teaching; AIME Past President R. W. Hunt; ASME Past President A. C. Humphreys, who not only was president of Stevens Institute of Technology but, of interest to Industrial Engineers, had conducted lectures on "some of the business features of engineering practice" for its Department of Economics of Engineering; ASCE Past President C. MacDonald; and Gano Dunn, who, in addition to the UES presidency, was a past president of AIEE—delivered appropriate and pertinent addresses. It was at these ceremonies that the identity of the donor was made known: ASME's Past President Ambrose Swasey.

UNITED ENGINEERING TRUSTEES

So important had the work of the Foundation become that, by 1930, the UES saw fit to change its own name to that of its creation: it officially became known as Engineering Foundation, Inc. The very next year, a further change was made, and the United Engineering Trustees, Inc. (UET) was established. UET is now—as it was in 1914 under its previous name—a great and potent unifying force in the engineering field. Its adhesive powers as well as its work and accomplishments have made it the *sine qua non* of the engineering profession. Many more engineers ought to be acquainted with its organization and operation, for very few practitioners are unaffected by its deeds and practices.

Essentially UET is a corporation whose aim is "to advance the engineering arts and sciences in all their branches and to maintain a free public engineering library." As simple as this sounds, the fields encompassed in its attempt "to advance the engineering arts and sciences" are quite numerous and diverse. Originally consisting of four "so-called Founder Societies," AIME, ASME, AIEE, and ASCE, there was added this year, for the first time in forty-two years, another national engineering society, the fifty-year-old American Institute of Chemical Engineers (AIChE), as a Founder Member. UET also admits other organizations, knows as Associates, with some limitations. Included in this category are such societies as AIIE, American Institute of Consulting Engineers, Society of Women Engineers, to mention but a few.

UET's Board of Trustees consists of members from the Founder Societies, who serve with no pecuniary compensation and who, together with the boards of the departments it may establish, have the power to appoint standing and special committees. The Executive Committee, Finance Committee, and Real Estate Committee are the standing committees. In line with its original duties of custodian of grants to the profession, the Board has the power to establish, maintain, or discontinue various endowments, reserves and other funds. Also, it is one of the duties of UET to "maintain and conduct as one of its departments a free public Engineering Library."

Specifically UET must "maintain a fund to be known as the Engineering Foundation Fund, and shall also maintain the Engineering Foundation as a department of the Corporation." The Foundation's researches are controlled by a Foundation Board, which is autonomous in the disbursement of its income, although subject to the ultimate approval of the Board of Trustees. In the thirty-year period from 1914 to 1934, for example, the Foundation spent, in research, about a million dollars from its own income and has attracted about fifteen times that amount as financial aid from industry and government plus laboratory facilities and personnel from the colleges. The Engineering Foundation is particularly concerned with starting projects of fundamental engineering interest which might possibly not otherwise be undertaken but which, when sufficiently advanced, attract interest and financial contributions from industry. These projects range from "Alloys of Iron Research" to the undertakings of the Welding Research Council; from a study by the Research Council on Corrosion to the work of the Engineers' Council for Professional Development. (Mention has already been made of AIIE participation with ECPD).

UET is the designated treasurer of ECPD. In addition to its services as custodian of funds for the financing of Engineering Foundation projects, UET owns the funds for the John Fritz Medal and the Daniel Guggenheim Medal.

Thus, UET is actively engaged in promoting research and educational activities of concern to all of the engineering societies, for, by its Charter, it is legally empowered to assist in "the advancement of the engineering arts and sciences in all their branches." And last but not least, it is concerned with the Enginering Societies Building—the "union home."

UET, under its present and its former names, has always been generous in providing space for societies when the need arose. A good example of this is the case of the Taylor Society, which, it must be remembered, was formed because of its desire to concentrate more fully than the members' interests of all in ASME would allow on certain specific problems. An editorial in the *Bulletin of the Taylor Society*, of April, 1930, in greeting ASME on its fiftieth anniversary, expressed its gratitude for the "helping hand" that was afforded and also for the fact that it was allowed "temporary location in one of the larger offices of ASME. As a matter of fact, SAM, an offshoot of the Taylor Society, once also had offices in the Engineering Societies Building. The latter, by its own volition never a "pure" engineering society, has, in the approximately dozen-and-a-half years that have elapsed since it maintained headquarters on the ground floor of the West 39th Street Building, been in at least three different locations in New York.

PLANS FOR LARGER ENGINEERING CENTER

However, for some time now, the Engineering Societies Building has become cramped for space. The continuing growth of the profession and the increasing number of more-and-more specialized engineering branches have made the present building quite inadequate. "Two of the societies have been forced to expand some of their departments in other buildings. Growing associate societies (not the four Founder Societies) have found it necessary to move from the building to acquire needed working space." The acceptance of newer societies—AIIE, for example—having offices elsewhere but which are and need to be an integral part of the engineering profession must be accommodated.

This concern for additional space has been the concern of engineering leaders for some time—most specifically in

1954. When Mr. Carnegie made his gift, about a half-century before this time, the four Founder Societies had 12,341 members. By the time the building was dedicated, there were about a third as many again. By 1954, the four Founders boasted a combined enrollment of about twelve times the 1904 figure. The figure of 12,341 probably represented *all* the engineers in the country at the time. Today, AIIE, celebrating its tenth anniversary, can boast of more than half that number as recognized professional practitioners of Industrial Engineering alone. Today, the Five Founder Societies have more than 179,000 members, the Associated Societies have a combined membership of more than 66,000. In addition, there are more than 36,000 student members.

In the fall of 1955, a Task Committee of Fifteen was appointed by the UET's Board of Trustees "to recommend a specific site for a new engineering center." In the months that followed, the question of a site together with the investigation of the enlargement of an Engineering Societies Center received serious consideration. Bids were received from numerous cities, and studies were made of various plans. On June 22, 1956, the Governing Boards of the Founder Societies and the AIChE, the prospective Fifth Founder Society, received the recommendation that "the plans for the new and enlarged Engineering Societies Center be made with ample optimism with respect to the future growth of the societies immediately involved." Further, it was recommended that "these facilities should be such as to attract and hold all of the engineering profession, thus fostering unity and cooperation along broad lines." As for the location of the structure, the American city chosen would have to be one that would allow the most efficient operation and the most effective achievement of goals sought. Opinions came from many engineering and industrial leaders.

Although opinion in this regard had been mixed—after all it was only natural that sectional pride should enter—there was a marked trend toward the retention of the Center in New York. Such opinion was exemplified by the thinking of a Californian, Former President Herbert Hoover, who wrote:

> I have long held that New York City is the only city where engineers can find a proper intellectual climate and the most facile association with the industrial and commercial groups with which they have so much to do.

New York was also the conclusion reached by the independent survey made by the management consulting firm of McKinsey and Company, whose services had been engaged in an objective attempt to find an answer.

On September 17, 1956, the Founder Societies approved the recommendations made by the Special Task Committee. These included, along with the recommendation cited as having been made during the previous June, the following:

> . . . The Engineering Societies Center be located in New York City. . . . The 39th to 40th Street site be continued in use as the site. . . . If rebuilding in that area proves impractical, a comparable site should then be sought in midtown New York. . . . The United Engineering Trustees, Inc., be authorized to take proper legal action for expansion by the addition of the American Institute of Chemical Engineers . . . when properly qualified . . . (and) . . . be authorized to raise money and accept contributions . . . place contributions in UET Capital Fund Assets; employ architects, engineers, and attorneys; let contracts for reconstruction of the present Engineering Societies Building and/or a new building or buildings . . . and operate and maintain the new Engineering Societies Center. . . .

When the recommendations of the Special Task Committee were approved, the feasibility of reconstruction on the present site was studied. Shreve, Lamb & Harmon Associates had for some time been consulting architects to UET, and the firm was quite aware of the existing potentialities. Nevertheless, a more thorough survey was made, and, in November 1956, Shreve, Lamb & Harmon Associates presented two alternatives. The first was negated on account of the City's set back ordinances: it had suggested razing the present building and erecting a new building fronting on West 40th Street by using land obtainable from the Engineers' Club. The second plan proposed the remodeling of the present building and the acquisition of additional property on 39th Street: this alternative was also abandoned upon receiving estimates from two reputable construction companies.

On February 12, 1957, UET voted to abandon the present headquarters, for reconstruction would interrupt operations, require moving to and from temporary quarters, renting at commercial rates for a period of eighteen months to two years, and, most important, "the building, as a remodeled makeshift, would not enhance the prestige of a proud profession." A search for another site was immediately instituted by a committee representing the Trustees. Its members, together with Dr. M. J. Kelly, who heads the Bell Telephone Laboratories, visited eight midtown New York locations. "Unanimous and enthusiastic agreement" was the result of the examination of a site which included the entire block-front on the west side of United Nations Plaza between 47th and 48th Street. And so this site—with its location in an international area entirely befitting the expanding role of the engineering profession—was purchased for $2,700,000 for the new United Engineering Center.

CHOOSING DESERVING SOCIETIES

Early in 1957, too, UET began consideration of engineering societies worthy of association in this combined effort of the profession. It is a deserved tribute to AIIE that it was early considered as one of the worthy Associates. In addition to other engineering societies chosen, such important services as Engineering Index, American Standards Association, and EJC were also selected. Shreve, Lamb & Harmon Associates were appointed architects, Jaros, Baum and Holles, mechanical engineers, and Seelye, Stevenson, Value and Knecht, structural engineers.

Ready for occupancy in the fall of 1960, the twenty-story building, superimposed on lower structures with landscaped surroundings extending to the East River, should provide about three times the space presently available in the 39th Street Building. Air-conditioned, the Center will take care of present needs and have sufficient facilities to accommodate future growth in the profession. Societies' space requirements, engineering meeting halls, committee rooms, cafeteria and dining rooms, and enlarged library and publication facilities are provided. In addition to an Engineering Hall of Fame "to perpetuate the contributions of great engineers to the effectiveness of American civilization," plans include exhibition space where the public can become acquainted with the advances in the engineering arts and sciences.

The new Center should have approximately 188,000 sq. ft. of usable space and about 59,000 sq. ft. of space given over to corridors, mechanical equipment, elevators, etc., making a total area of about 250,000 sq. ft. The cost of the building is presently estimated at no more than $30 per sq. ft. This amount plus the $2,700,000, mentioned above for the purchase of the land, will make the total cost of the Center about $10,000,000. Of course, this $10,000,000 will and has necessitated a fund-raising venture which the engineering profession cannot afford to overlook. However, the amount needed by contributions from the profession's practitioners and friends will be aided by the fact that $2 million will be available from UET real estate assets including the sale of the 39th Street Building and $5 million will be sought from business and industry. Of course, the remaining $3 million is the obligation of the profession.

At an Industry Campaign Meeting of Sponsors for the United Engineering Center Building Fund held at the Waldorf-Astoria on November 21, 1957, some leading engineers and industrialists made some vital remarks on the importance and significance of the combined venture. Former President Hoover, the Campaign's Honorary Chairman, asserted that this was a matter "of national importance," for "the activities of these societies are of vital importance to the American people, to the engineers and to the industries." President Killian of MIT recognized the plan as "belatedly, a great national effort to properly recognize, to deploy and strengthen the resources of engineering and science in the United States." Deputy Secretary of Defense Donald Quarles looked upon the united effort as "a thing of utmost importance to the country, to its long-term security, to its long-term soundness." General Electric's Ralph Cordiner was certain that "this kind of expenditure, if it's wise—which it is—is going to be reflected in better products, better results, a better standard of living," while General Motors' Alfred P. Sloan, Jr., simply called it "a 'must.' "

AIIE'S ROLE

And what of AIIE's role? Even though its share is approximately $70,000, not quite 2.5 percent of the total to be raised by the engineering profession itself, less than one-fourth of what the Bell System alone has already pledged, and not even one-tenth of the individual goal of either ASME or ASCE, the AIIE's National Board, mindful of the interests and financial status of its members and chapters, wisely weighed the pros and cons at its meeting in Los Angeles last June.

In an excellent study, in typical engineering economics fashion, which was made by Mr. John Bridgewater and which was brought to the attention of the Board, the advantages and disadvantages of AIIE's move with the other engineering societies or its retention of status quo and isolation were discussed. The pros and cons bear repeating here:

Pro:

1. Increased prestige, recognition, and acceptance.

   These would result from AIIE's close physical association with the other engineering societies. Not only would the Institute but the field would be guarded, by engineers, by industry, by commerce, by government, by the public, with equal status along with the rest of the established and reputable branches of engineering. This would come from AIIE's sharing of the Engineering Center, its listing with the other engineering societies, its joint sponsorship of events, its representation on many major joint committees, and its close contact with other engineers and engineering societies.

   Most important, a decision to remain "outside" might mean permanent isolation and a strong handicap in obtaining the recognition so necessary to its members.
2. Better operation and service.

   These would come from the effective use of the efficient facilities and services in the new Center—from the Engineering Library through IBM facilities. Better access to public relations resources and media centered in New York. Joint benefit from gifts and grants to the engineering profession. Better access and closer contacts with corporate and industrial managements, the national center of which is in New York. Better access to trade associations and management societies (e.g., American Management Association, etc.). Increased representation and association with key engineering professional committees (EJC, ECPD, etc.) with which AIIE already has contact. Closer relations with not only national but international engineering and other groups.

   Some of these are not at all possible in AIIE's present location and others are only possible by means of financial expenditures for frequent trips to New York by officers.
3. Better and more effective use of manpower.

   These would be made possible by the availability of building facilities (committee rooms, auditorium, library facilities) and services (high-volume duplication, mailing, receiving-and-shipping, IBM processing), better access to AIIE Headquarters by National Officers, committee members, and general membership, opportunity to exert more influence on joint engineering societies committees.
4. Greater accessibility—particularly to members.

   Outside of the many more airlines, railroads, bus lines, with more frequent service and with less transfers and delays, the location of National Headquarters in New York near the UN Building would naturally invite more members to visit than is now being done.
5. Isolation avoidance.

   The chance to join with the other members of the engineering profession comes now: it may never come again.

6. Income increase.
   This would result from an estimated 12½% increase in membership rather than the present 10, from an increase from JOURNAL advertising, and additional income from joint conferences, seminars, and courses. Then, too, there are the possible gift-sharings from donations to the joint societies. These increases were itemized, and a 32% increase in gross income is a distinct possibility.

Con:

1. Higher Operating costs in New York.
   Admittedly some operating costs in New York are higher than those presently encountered. A breakdown with the extra cost involved in the moving—and without consideration to the economies that will result from the accessibility to more highly competitive suppliers of forms, stationery, etc., and with a complete disregard to the numerous items that can be made as joint purchases with other engineering societies—shows, less than 20% increase.
2. New York is not the geographic center of membership.
   Despite the fact that a circle with a radius of 500 miles around New York takes in a good part of the Atlantic Ocean, such a circle would encompass 30% of the present membership as compared to the present location's 40. More important, however, is the factor of accessibility, and this is in New York's favor. In addition, the move with the other engineering societies would probably "sell" AIIE to many in the as yet untapped area along the Eastern seaboard.
3. Some societies are moving away from New York.
   There is no evidence of any such trend. Admittedly a tool engineers society has moved to the center of its industry (Detroit) and a group of geophysical engineers has moved to its center (Fort Worth), but these hardly constitute a national trend. As a matter of fact, New York now has some 25 engineering and business societies and over 1,000 trade and similar associations—many of which AIIE would most naturally want to contact from time to time.
4. Move problems and displaced personnel.
   The move is a one-time expense. As for a possible displacement of clerical personnel unwilling to move to New York, this is, of course, a problem but not a serious one. There is a good market in the present location for such skills, and there should be no trouble in placing such personnel in satisfactory positions.

Weighing the pros and cons, the decision was obvious, and Mr. Henry M. Owades was appointed to coordinate AIIE's efforts. Within two weeks, the AIIE's pledge cards totaled $4,200.

Probably no move since that made by founder Wyllis Stanton ten years ago can match this latest decision of AIIE to accept its responsibilities as a member of the engineering community. No member of AIIE can, ought, or should do less!

CONFERENCE AND CONVENTION

The Tenth Annual National Conference and Convention of AIIE will be held:

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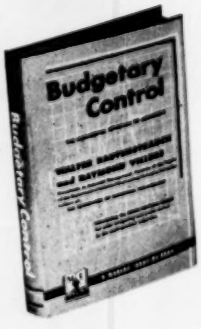

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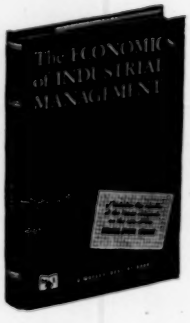

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A Scheduling Problem

An Analytical Solution Based Upon Two Machines, n Jobs, Arbitrary Start and Stop Lags, and Common Sequence

by L. G. MITTEN

Professor of Industrial Engineering, The Technological Institute, Northwestern University

THE GANTT chart scheduling problem involves the sequential scheduling of a set of activities over a set of facilities. In the production context, the problem may be stated roughly as follows: n jobs are to be scheduled on m machines; the time required for each job on each machine is given along with the sequence of operations (i.e., machines) for the job; relationships between starting and completion times of successive operations for a given job may be specified; the efficiency of a schedule is judged in terms of machine utilization, or idle machine time, or total time to complete all jobs, or some similar criterion.

The practical importance of the Gantt chart scheduling problem can hardly be underestimated. In various forms and contexts it is encountered many thousands of times daily in enterprises throughout the world. To date, the problem has yielded only slightly to formal analysis, and the practical scheduler has had to rely almost wholly on his intuition and experience in attempting to construct optimal schedules.

Bellman (1) and Johnson (3) have treated a rather severely restricted version of the problem involving the scheduling of n jobs on two (and in special cases, three) machines. In their formulation, each job is to be run first on one machine (say, machine I) and then on the other (say, machine II); a job is started on machine II as soon as possible after its completion on machine I. Simple rules are given for finding the schedule which minimizes total time to complete all jobs on both machines (which is equivalent to minimizing machine idle time). The author (4) has treated a somewhat less restrictive case which is applicable to a wider variety of problems. Both of the preceding problems are special cases of the more general formulation presented here.

STATEMENT OF THE PROBLEM

Consider two machines (I and II) and n jobs ($1, 2, \ldots, n$), with the jobs to be run in the sequence $\mathbf{S}_1 = [1, 2, \ldots, n]$ (i.e., job 1 is run first, job 2 second, ..., and job n last). We assume that each job is to be run first on machine I and then on machine II, using the same sequence ($\mathbf{S}_1$) on both machines. Let A_i and B_i be (respectively) the time required by job i on machine I and machine II. Associated with each job i is a "start-lag" a_i (≥ 0) and a "stop-lag" b_i; the start-lag (a_i) is the minimum time which must elapse between starting job i on machine I and starting it on machine II, while the stop-lag (b_i) is the minimum time which must elapse between completing job i on machine I and completing it on machine II.

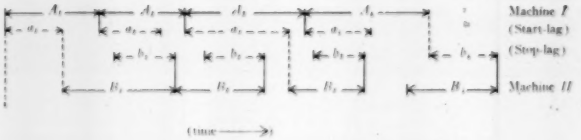
The following scheduling rules characterize the Gantt chart problem dealt with in this paper:

1. On machine I, the jobs are to be run in the sequence $\mathbf{S}_1$ without interruption (i.e., job i is started on machine I immediately on the completion of job i-1 on machine I);

2. On machine II, job i is started as soon as possible after the completion of job i-1 on machine II—subject to the provisions that job i may not be started on machine II less than a_i time units after it was started on machine I, and job i may not be completed on machine II less than b_i time units after its completion on machine I.

In the following we shall let x_i be the amount of idle time on machine II immediately preceding the start of job i on machine II.

Figure 1 shows a typical two machine Gantt chart schedule involving four jobs with specified start and stop lags. The excerpts from this schedule shown in Figure 2 illustrate the way in which the start and stop lags determine the time at which the various jobs are run on machine II, given the common sequence $\mathbf{S}_1$. In Figure 2 (c) we see that we are able to start job 2 on machine II immediately after the completion of job 1 on machine II, since the starting time of 2 on II is more than a_2 time units after the start of 2 on I and the completion of 2 on



A_i = Time for job i on machine I (including set-up, tear-down, and running time)
B_i = Time for job i on machine II (including set-up, tear-down, and running time)
a_i = Start-lag for job i $\quad$ b_i = Stop-lag for job i

FIG. 1. Typical Two Machine Gantt Chart with Start and Stop Lags.

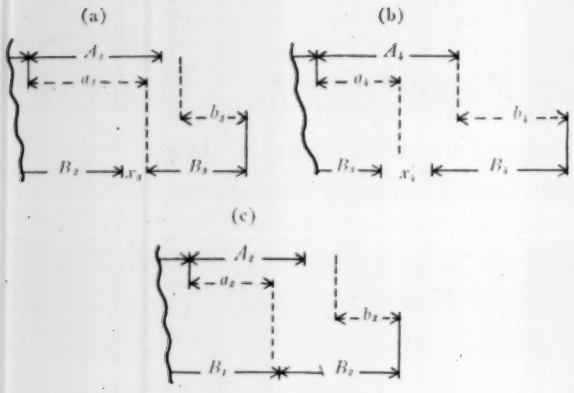


FIG. 2. x_i = Idle time immediately preceding start of job i on machine II.

II is more than b_2 time units after the completion of *2* on I. (Note that $x_2 = 0$ since there is no idle time on II between the completion of *1* and the start of *2*.)

In Figure 2 (a) the start-lag (a_3) controls the starting time for job *3* on machine II. The stop-lag restriction on *3* is met, since *3* is completed on II more than b_3 time units after the completion of *3* on I. The idle time preceding the start of *3* on II is shown as x_3 in the figure. As seen in Fig. 2 (b), it is the stop-lag (b_i) which controls the time during which the job *4* is run on machine II: were job *4* started on II immediately after the completion of *3* on II, both the start and stop-lag restrictions would be violated; and were *4* started on II a_4 time units after the start of *4* on I (which would meet the start-lag restriction) the stop-lag restriction on *4* would not be met (since *4* would be completed on II less than b_4 time units after the completion of *4* on I). The idle time preceding *4* on II is shown as x_4 in Figure 2 (b).

Referring to Figure 1, it is seen that machine II is idle for an initial period between the start of job *1* on machine I and the start of *1* on machine II. We let x_1 denote the duration of this initial period of idle time.

It might be noted that the Bellman-Johnson sequencing problem is a special case of the above model in which $a_i = A_i$ and/or $b_i = B_i$ for all i. When $a_i = b_i$ for all i we obtain the special case previously treated by the author (4).

The major restrictions inherent in the present formulation (and in the special cases previously cited, as well) are the limitation of consideration to two machines, and the requirement that the same sequence be used on both machines. As will be shown in the next section, the restriction of attention to two machines is not nearly as serious a limitation as one might have anticipated. The common sequence restriction, however, may still lead to unnecessary idle time and delays in some situations. The "independent sequence" two-machine Gantt chart problem appears to be quite complex and will not be considered further in this paper.

USE OF START AND STOP LAGS

The start and stop lags incorporated in the present model permit one to treat a variety of practical Gantt chart problems which previous models were unable to handle. Several such applications will be discussed briefly in this section.

OVERLAPPING PRODUCTION

In some situations it is possible to start production of a given job on machine II before the completion of production of the job on machine I; This is known as "overlapping" production. Such circumstances occur frequently in scheduling engineering work, research and development work, construction projects, etc. as well as in industrial production activities. Normally, some portion of activity I must be completed before activity II can be started (in the production context we speak of accumulating a "minimum initial backlog" for the job in question). Such overlapping is easily accomplished by a proper choice of the start and stop lags. For example, suppose that production may be overlapped on job i—as long as a minimum backlog of two hours of production from machine I is always maintained as a cushion between the two operations (machines); taking $a_i = b_i = 2$ hours will assure that the two hour cushion is always maintained. Again, suppose that on engineering project i we may start drafting (operation II) anytime after the first three weeks of design work (operation I) have been completed, but that drafting may not be completed before design is completed; these conditions call for $a_i = 3$ weeks and $b_i = 0$. As a final example, suppose that on construction project i the exterior painting (operation II) can begin no sooner than four months after the carpentry work (operation I) was started, but that once started the painting may proceed without further regard to the progress of the carpenters; we then take $a_i = 4$ months and $b_i = -\infty$ (indicating no effective stop-lag). (We should recall that although b_i may be negative, a_i must be zero or positive.)

TRANSPORT TIME BETWEEN MACHINES

It is clear from the above discussion that any transport time (or other delays) between machines may be easily incorporated in the values of the a_i's and b_i's.

SCHEDULING BOTTLENECK MACHINES

In a large number of situations, a small number of machines (or other operations) cause the vast majority of the scheduling problems; these highly loaded machines are often referred to as "bottleneck" machines. Suppose two machines (say, I and II) create the most serious bottlenecks, and that after being run on machine I jobs may (or may not) be routed over a variety of intermediate (non-bottleneck) machines before being started on machine II. We may then let a_i = (time to complete intermediate operations on job i) + (any initial minimum backlog required); likewise, b_i = (time to complete in-

termediate operations) + (any minimum final backlog required). By concentrating attention on the two most serious bottlenecks, the two-machine Gantt chart problem may be used to provide an optimal scheduling framework for a facility employing a large number of machines.

As seen in the foregoing illustrations, the start and stop lags give considerable flexibility to the scheduling model under discussion, and special choices for the values of a_i and b_i permit one to reflect a variety of conditions (e.g., for non-overlapping production we must have $a_i \geqq A_i$).

THE CRITERION MEASURE

We shall take the total time required to complete all n jobs on both machines as a measure of the efficiency of a schedule. Since minimizing the idle time on machine *II* is equivalent to minimizing the total time to complete all jobs on both machines (see Figure 1), we shall use

$$C = \sum_{i=1}^{n} x_i \ (= \text{total idle time on machine } II) \quad \text{Eq. 1.}$$

as the criterion function to be minimized. The rules given in the next section yield a schedule which minimizes C.

THE OPTIMAL SCHEDULE

The procedure for obtaining the optimal schedule is perhaps best explained with the aid of a simple numerical example which will illustrate both the computations required and a convenient tabular form in which the various steps may be carried out.

In Table 1, column 1 gives the job number, column 2 the start-lag, column 3 the time on machine *I*, column 4 the stop lag, and column 5 the time on machine *II* for each of the five jobs. The entries in the first five columns represent the given data for the problem. To find the optimal sequence, the following steps are carried out in the table:

1. In each row, subtract the value in column 3 from the value in column 2 and enter the result in column 6;
2. In each row, subtract the value in column 5 from the value in column 4 and enter the result in column 7;
3. In each row, take the (algebraically) larger of the two numbers in columns 6 and 7 and enter it in column 8;
4. In each row, put an X in column 10 if the value in column 3 is less than the value in column 5; otherwise (i.e., if $A_i \geqq B_i$) put an X in column 9;
5. In each row with an X in column 10, add the value in column 3 to the value in column 8 and enter the sum in column 9;

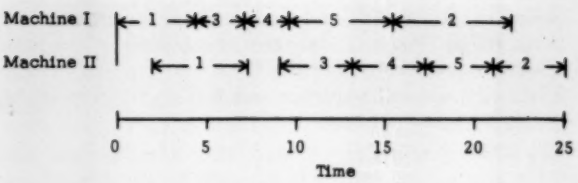


FIG. 3. The Optimal Schedule.

6. In each row with an X in column 9, add the value in column 5 to the value in column 8 and enter the sum in column 10;
7. The job (row) with the smallest value in column 9 is run first; the job with the next smallest value in column 9 is run second, etc.; the job (row) with the smallest value in column 10 is run last; the job with the second smallest value in column 10 is run next to last, etc.; this running order is entered in column 11.

The sequence indicated by the running order in column 11 of Table 1 leads to the schedule shown in Figure 3. This schedule requires a total of 25 time units to complete all five jobs on both machines; the idle time on machine *II* is 3 time units. No other common sequence yields a smaller amount of idle time (nor a shorter total time) than the given schedule. (In the present example, no other schedule of *any* type which meets the start and stop lag restrictions yields a smaller amount of idle time or a shorter total time.)

MATHEMATICAL DEVELOPMENT

In this section we present the formal mathematical statement of the problem and the proof of the optimality of the schedule derived by the procedure of the preceding section.

For a given set of n jobs, let the jobs be arbitrarily numbered with the first n positive integers. Then $\boldsymbol{S}_1 = \{1, 2, \cdots, n\}$ represents one of the $n!$ possible sequences in which the n jobs could be run on machines *I* and *II* (using the same sequence on both machines). Let $\mathfrak{y} = \{\boldsymbol{S}\}$ be the set of all possible sequences of n jobs (i.e., the elements of $\mathfrak{y}$ are $\boldsymbol{S}_1$ plus the $n!-1$ permutations of $\boldsymbol{S}_1$). For every $\boldsymbol{S} \in \mathfrak{y}$, the criterion function C defined in Eq. 1. will take on a value $C(\boldsymbol{S})$. The set of optimal sequences, $\mathfrak{y}' (\subset \mathfrak{y})$, is a set such that for every $\boldsymbol{S}' \in \mathfrak{y}'$ and for every $\boldsymbol{S} \in \mathfrak{y}$ we have $C(\boldsymbol{S}') \leqq C(\boldsymbol{S})$.

We assume that the previously interpreted real con-

TABLE 1

Example of a Two Machine Gantt Chart Scheduling Problem

Given Data					6 = 2 − 3	7 = 4 − 5	8 = max (6, 7)	9 = 8 + 3	10 = 8 + 5	11
1	2	3	4	5						
i	a_i	A_i	b_i	B_i	$a_i - A_i$	$b_i - B_i$	m_i	$m_i + A_i$	$m_i + B_i$	Running order
1	1	4	3	5	−3	−2	−2	2	X	1
2	4	7	1	4	−3	−3	−3	X	1	5
3	4	3	6	4	1	2	2	5	X	2
4	6	2	4	4	4	0	4	6	X	3
5	4	6	3	4	−2	−1	−1	X	3	4

stants a_i, A_i, $B_i \geqq 0$, and b_i are given for every $i \in \boldsymbol{S}$ (with $\boldsymbol{S} \in \mathfrak{y}$). For any constant or variable, z, we take $z_i = 0$ whenever $i \notin \boldsymbol{S}$. Let $\boldsymbol{S} = \{r, k, \cdots, q\} \in \mathfrak{y}$ be any arbitrarily selected sequence and for any $i \in \boldsymbol{S}$ let i' be the job immediately preceding i in $\boldsymbol{S}$ (e.g., if r is the first and k the second element of $\boldsymbol{S}$, then $k' = r$). Note that if r is the first element of $\boldsymbol{S}$ then $r' \notin \boldsymbol{S}$ and so $z_{r'} = 0$ for any variable or constant z. As a matter of notational convenience, for fixed $\boldsymbol{S}$ and for every variable or constant z we define

$$\bar{z}_i = z_i + \sum_{j \in \boldsymbol{i'}} z_j,$$

where $\boldsymbol{i'}$ is the set of all jobs which precede i in $\boldsymbol{S}$.

In the following, $\boldsymbol{S}$ is an arbitrary element of $\mathfrak{y}$ which is held fixed throughout the discussion. Let t_i' and t_i be (respectively) the time at which job i starts on machine I and on machine II for the given sequence $\boldsymbol{S}$; by our convention, $t'_{r'} = t_{r'} = 0$ when r is the first element of $\boldsymbol{S}$. The idle time, x_i, on machine II between the completion of job i' and the start of job i is given by

$$x_i = t_i - (t_{i'} + B_{i'}). \qquad \text{Eq. 2.}$$

With the above definitions and interpretations, the Gantt chart scheduling problem under discussion is completely defined by the recursive relations

$$t_i' = t_{i'}' + A_{i'}', \qquad \text{Eq. 3.}$$

and

$$t_i = \max\,[t_i' + a_i, t_i' + A_i + b_i - B_i, t_{i'} + B_{i'}]. \qquad \text{Eq. 4.}$$

[Eq. 4. simply states that job i starts on machine II either a_i time units after starting on I or immediately on completion of job i' on II, or that job i is completed on machine II b_i time units after its completion on machine I—whichever condition yields the latest starting time for i on II.] It follows directly from Eq. 2. and Eq. 3. that $\bar{x}_i = t_i - \overline{B}_{i'}$ and $t_i' = \overline{A}_{i'}$. Letting $m_i = \max\,[a_i - A_i, b_i - B_i]$ we may write Eq. 4. as

$$\begin{aligned} t_i &= \max\,[t_i' + A_i + m_i, t_{i'} + B_{i'}] \\ &= \max\,[\overline{A}_i + m_i, t_{i'} + B_{i'}]. \end{aligned} \qquad \text{Eq. 5.}$$

Substituting from Eq. 5. into the expression for $\bar{x}_i$, we obtain

$$\begin{aligned} \bar{x}_i &= \max\,[\overline{A}_i - \overline{B}_{i'} + m_i, t_{i'} + B_{i'} - \overline{B}_{i'}] \\ &= \max\,[\overline{A}_i - \overline{B}_i + B_i + m_i, \bar{x}_{i'}] \\ &= \max\,[F_i, \bar{x}_{i'}] \end{aligned} \qquad \text{Eq. 6.}$$

where we take $F_i = \overline{A}_i - \overline{B}_i + B_i + m_i$.

If r is the first element of $\boldsymbol{S}$, then $\bar{x}_{r'} = 0$ and $F_r \geqq 0$, and so $\bar{x}_r = F_r$. Let $k' = r$ (i.e., k is the second element of $\boldsymbol{S}$); taking $i = k$ and $\bar{x}_{k'} = \bar{x}_r = F_r$ in Eq. 6. we obtain $\bar{x}_k = \max\,[F_k, F_r]$. Proceeding recursively in this fashion for each succeeding element of $\boldsymbol{S}$, we finally obtain for the last element of $\boldsymbol{S}$ (say q),

$$C(\boldsymbol{S}) = \bar{x}_q = \max_{1 \leqq u \leqq n}\,[F_u]. \qquad \text{Eq. 7.}$$

Eq. 7. provides a formula for computing $C(\boldsymbol{S})$ for any $\boldsymbol{S} \in \mathfrak{y}$. It should be noted that the values of the F_u's depend on the sequence and that F_u for the sequence $\boldsymbol{S}$ is not necessarily equal to F_u' for the sequence $\boldsymbol{S}'$ when $\boldsymbol{S} \neq \boldsymbol{S}'$.

Now with the fixed numbering of the n jobs, consider the two disjoint (and collectively exhaustive) sets $\boldsymbol{s} = \{i \mid A_i < B_i\}$, and $\boldsymbol{s}' = \{i \mid A_i \geqq B_i\}$. Let $\boldsymbol{s}^* = \{v, k, \cdots, g\}$ be any ordering of the elements of $\boldsymbol{s}$ such that $A_v + m_v \leqq A_k + m_k \leqq \cdots \leqq A_g + m_g$, and let $\boldsymbol{s}'^* = \{q, h, \cdots, w\}$ be any ordering of the elements of $\boldsymbol{s}'$ such that $B_q + m_q \geqq B_h + m_h \geqq \cdots \geqq B_w + m_w$. Finally, let $\boldsymbol{S}^* = \{v, k, \cdots, g, q, h, \cdots, w\}$ and let $\mathfrak{y}^* = \{\boldsymbol{S}^*\}$ be the set of all such sequences $\boldsymbol{S}^*$. Then the validity of the solution procedure is established by the following.

Theorem

Every $\boldsymbol{S}^* \in \mathfrak{y}^*$ is an optimal sequence—i.e., for every $\boldsymbol{S}^* \in \mathfrak{y}^*$ and for every $\boldsymbol{S}'' \in \mathfrak{y}$ we have $C(\boldsymbol{S}^*) \leqq C(\boldsymbol{S}'')$.

Proof: Consider any arbitrary $\boldsymbol{S}^* \in \mathfrak{y}^*$ and any arbitrary $\boldsymbol{S}'' \in \mathfrak{y}$. If $\boldsymbol{S}^* = \boldsymbol{S}''$ then $C(\boldsymbol{S}^*) \leqq C(\boldsymbol{S}'')$ trivially, so assume $\boldsymbol{S}^* \neq \boldsymbol{S}''$. It follows from the definition of $\boldsymbol{S}^*$ that $\boldsymbol{S}''$ may be obtained from $\boldsymbol{S}^*$ by a series of transpositions of adjacent jobs such that for each transposition (e.g. interchanging the positions of jobs i and j where i immediately precedes j) one of the following relations holds between the two jobs:

$$\begin{aligned} R1 &= [(i, j \in \boldsymbol{s}) \text{ and } (A_i + m_i \geqq A_j + m_j)], \text{ or} \\ R2 &= [(i, j \in \boldsymbol{s}') \text{ and } (B_i + m_i \leqq B_j + m_j)], \text{ or} \\ R3 &= [(j \in \boldsymbol{s}) \text{ and } (i \in \boldsymbol{s}')]. \end{aligned}$$

Let $\boldsymbol{S} = \{\cdots, i, j, \cdots,\}$ be the sequence obtained at some stage in the process of making such a series of transpositions, and let $\boldsymbol{S}' = \{\cdots, j, i, \cdots,\}$ be the next sequence in the series—with one of the relations R1, R2, or R3 holding between i and j. To prove the theorem it will suffice to show that for such a typical stage in the process we have $C(\boldsymbol{S}) \leqq C(\boldsymbol{S}')$. For the sequence $\boldsymbol{S}$ we have

$$C(\boldsymbol{S}) = \max_{1 \leqq u \leqq n}\,[F_u]$$

and for the sequence $\boldsymbol{S}'$ we may take

$$C(\boldsymbol{S}') = \max_{1 \leqq u \leqq n}\,[F_u']$$

for suitably defined F_u'. In fact, if we take $E_u = A_u - B_u$ and $\overline{E}_u = \overline{A}_u - \overline{B}_u$ it is readily verified that

$$F_u' = \begin{Bmatrix} F_u \text{ for every } u \neq i, j \\ F_u + E_j \text{ for } u = i \\ F_u - E_i \text{ for } u = j \end{Bmatrix}. \qquad \text{Eq. 8.}$$

Now let $\boldsymbol{P} = \{F_i, F_j\}$, $\boldsymbol{P}' = \{F_i', F_j'\}$, and $\boldsymbol{Q} = \{F_u \mid u \neq i, j\} = \{F_u' \mid u \neq i, j\}$. Then $C(\boldsymbol{S}) = \max\,[\boldsymbol{P} \cup \boldsymbol{Q}]$ and $C(\boldsymbol{S}') = \max\,[\boldsymbol{P}' \cup \boldsymbol{Q}]$. If $\max\,[\boldsymbol{P}] \geqq \max\,[\boldsymbol{P}']$ then we will have $\max\,[\boldsymbol{P} \cup \boldsymbol{Q}] \geqq \max\,[\boldsymbol{P}' \cup \boldsymbol{Q}]$ and thus $C(\boldsymbol{S}) \geqq C(\boldsymbol{S}')$ and the theorem will be proved. To show that

max $[P] \geqq \max [P']$ we take

$$L = \max [B_i + m_i - E_j, B_j + m_j]$$

and

$$R = \max [B_i + m_i, B_j + m_j - E_i]$$

so that we may write max $[P] = \overline{E}_j + L$ and max $[P'] = \overline{E}_j + R$. Then it will suffice to show that $L \geqq R$ in the three mutually exclusive and exhaustive cases listed below.

Case (a)—$R1$ holds: Subtracting $(E_i + E_j)$ from both sides of the inequality $A_i + m_i \geqq A_j + m_j$ and simplifying yields $B_i + m_i - E_j \geqq B_j + m_j - E_i$; further, since $j \in s$ we have $E_j < 0$ and $B_i + m_i - E_j > B_i + m_i$; therefore, $L \geqq R$ as required.

Case (b)—$R2$ holds: since $i \in s'$ we have $E_i \geqq 0$ and so $B_j + m_j \geqq B_j + m_j - E_i$; this result and the given inequality $B_j + m_j \geqq B_i + m_i$ prove that $L \geqq R$.

Case (c)—$R3$ holds: since $j \in s$, $E_j < 0$ and so $B_i + m_i - E_j > B_i + m_i$; since $i \in s'$, $E_i \geqq 0$ and so $B_j + m_j \geqq B_j + m_j - E_i$; thus, for every element of R there is an element of L which is at least as large, and so $L \geqq R$.

Having shown that $L \geqq R$ in all three cases, the theorem stands proved.

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Systems Engineering in The Engineering Curriculum

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AMONG the general purposes of education are to develop men who have confidence in themselves and inspire confidence in others, men who can face successfully all the circumstances in the operation of an enterprise, business or otherwise. Stated in different terms, college graduates should be able to handle competently both short-term, or day-to-day decisions, and in addition evaluate and select long-term courses of action. For optimum decision making of either type these men need self-confidence, vision, and adequate background. It is the thesis of the writer that studies in systems engineering can contribute in a significant manner to the self-confidence of the future engineer, to the development of his imagination and of his ability to abstract, and to his store of knowledge.

DEFINITION

Systems Engineering is expressed by two words, system and engineering. Webster defines system as "an assemblage of objects united by some form of regular interaction or interdependence," and engineering as "the art and science by which the properties of matter and the sources of power in nature are made useful to man in structures, machines, and manufactured products." While other definitions of these two words have been given, the ones mentioned will well serve to build a picture of the concept under discussion.

The definition of the word system includes the word "assemblage," indicating that a system contains more than one component, and the expression "united by . . . interaction or interdependence," showing that systems are not just groups of individual things or concepts like a hill of sand, but groups in which each component part interacts with or is dependent on the other. If, then, we accept the definition of engineering as that art and science that forms useful products from nature's matter and energy, systems engineering is the art and science by which nature, man, and machines are arranged to form an assemblage united by interaction and interdependence to create products from nature's materials and energy sources. In other words, systems engineering is the art and science of designing or analyzing productive man-machine-environment "systems."

To some who have received the traditional engineering education as civil, mechanical, electrical or chemical engineers, this concept of "systems" or "systems engineering" may sound strange or even heretical, but actually these people are more familiar with this concept than they realize. Every civil engineer, who has ever planned a building, made it to fit certain equipment and made it large enough for certain goods to be moved around in it, has done a phase of systems engineering. So did the mechanical engineer who made certain that the controls of a machine were easily accessible for an operator, and the electrical engineer who studied a power system or analyzed the input-output requirements of an electronic device. But while the classical divisions of engineering deal to an extent with things as a whole, it is the industrial and the electronics engineer who come closest to systems engineering in that they consider a

whole process and its ramifications. Yet even here there is a difference in the scope of endeavor. For instance, while the Industrial Engineer deals chiefly with production processes, the scope of the systems engineer is much broader, and embraces functions even at the top management level. The systems engineer is the necessary assistant to top management; he represents the most modern developments in engineering. He must be something of an electrical, mechanical and civil engineer, but also he is expected to be an economist, a mathematician and a physicist. He deals with systems of man-machine-environment interaction, be it in an industrial enterprise or an office, a military organization or a transportation line.

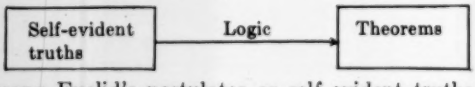
ADVANTAGES

Perhaps one of the most important advantages a student can get from studies in systems engineering is the ability to abstract. Through these studies he will learn that we are living in a man-made world of ideas and ideals and that not all systems with which he will be concerned are physical, nor are all laws he will have to obey unchangeable. In mathematics the word "system" usually means a set of laws. Mathematical laws, for example, are man-made and, unlike the law of gravity, they can be changed if and when man decides to develop a different system.

In his studies in systems engineering the student should learn that systems are themselves sub-systems of other larger systems. Whenever intersystem and intrasystem interactions exist, we need working theories to explain certain phenomena and to help in the investigation of others. It is important that the engineering student realize early in his education that, when in science we talk of theorems, we must keep in mind that these theorems are man-made. For example, consider the case of mathematics. Since proof of a theorem is derived from previous theorems, obviously the first group of theorems (or postulates) cannot be proved. Thus any system must start with *unproved theorems* from which all other theorems will be proved. Likewise, such a system must start with certain undefined terms from which all other terms may be defined.

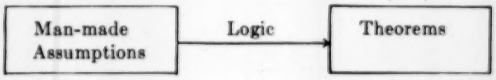
EUCLID'S SYSTEM

Euclid's system rested on unproved propositions and undefined terms. Though today we may disagree with the idea of a self-evident truth, fundamentally Euclid believed any proposition is either a "self-evident truth" or something which must be derived logically from self-evident truths (theorems). This concept can be shown by the following relationship:



Among Euclid's postulates or self-evident truths was the postulate concerning parallelism: "Through any given point which is not on a given line one and only one line can be drawn which is parallel to the given line." Because this postulate was not as self-evident as many of the others, Euclid reluctantly listed it as such only after unsuccessfully trying to prove it from his other postulates. Other mathematicians were also dissatisfied, and they likewise tried to prove the proposition. Over a period of several centuries however, they too failed.

After two thousand years of failure, early in the nineteenth century several mathematicians came to the conclusion that the reason for this failure was a false attitude toward the nature of postulates. These mathematicians reasoned that postulates were not self-evident truths at all, but rather "man-made assumptions." Schematically, they believed the procedure of proving theorems was as follows:



Generally speaking, in a man-made system we can prove any theorem if we are given the chance to establish our axioms. Furthermore, in the transition from man-made assumptions to theorems logic must be employed. If we keep everything else the same and vary logic, we will obviously arrive at a different set of theorems. On this rationale, the Euclidean system has been challenged by mathematicians like Gauss and Riemann, who developed new kinds of geometry known as non-Euclidean.

These new geometries, which showed that postulates are independent in nature and therefore that contradictory postulates may exist in complete harmony, led to an examination of the postulates of algebra. The alternative approaches presented gave rise to new algebras as well as other new mathematical systems. One of these new algebras, and probably the most important, was Boolean algebra, established by George Boole in 1847. Boole based his algebra on a set of eleven postulates. When Boolean algebra is viewed in the light of classical algebra, we see that some of the former's postulates hold, some do not hold, and some others are meaningless. Because it has been established, however. that postulates are simply man-made assumptions, we have the right to make them and derive theorems from them, provided there are no contradictions in the system.

MAN-MACHINE INTERACTIONS

Even if this notion of human independence in system definition, system freedom, and system development is the only advantage the engineer can get from studies in this field of technology, then his time would really be worth-while. There are indications, however, that this knowledge will not be his only benefit. Indeed, during the past few years large scale systems involving complex man-machine interactions have become a subject of study and analysis. Engineers have begun to treat man as a machine component. Through his senses, the operation inputs information as to the present status of the machine, or process. These data are usually taken from the

output of the machine. The measuring and information-transfer units of the human can be compared to the feedback means of a control mechanism. The information in question is processed through the nervous system and checked against some standard. After the comparison is made, and if corrective action is necessary, the human through his psychomotor activity will activate the control devices.

The engineering student should be taught early in his studies that this man-machine interaction is subject to constraints because of the capabilities of the two subsystems, man and machine, and also because of the interference of environmental factors. Such environmental factors as noise, radiation, vibration, temperature, humidity, etc. may disrupt or harm the man-machine communication process. They may also reduce the respective capabilities of men and machines. Although modern technology provides the means of controlling the environment, there is always a time lag between the day a new process is developed and the day its particular environment is controlled. It is part of the job of the engineer to provide for environmental optimization.

Apart from the environmental interference, production men have often found that they, as humans, could no longer keep up with the demands of the system as processes became more complex. It was then necessary to devise a substitute for the human operator, in other words, to build devices able to undertake the controlling functions of the system. To the first engineers involved in design for automation this meant that something had to be devised to simulate the human senses, brain, and motor skill, in functions such as proportioning, anticipating, and integrating. It was also necessary to devise something able to take the place of the operator in the moving of the valves or control levers. Hence the concept of the closed loop has evolved. No matter what may be his special field, no engineering student should ever complete his studies without being introduced to the theory and application of feedback mechanisms.

ELECTRONIC COMPUTATION

The engineering student should become very efficient in electronic computation. Computers hold the key to new systems of organization for the sprawling giants of industry, commerce, and government—structures whose explosive growth over the past three generations has sometimes seemed to defy orderly control by small groups of men at their tops. In early 1954 it was estimated that perhaps 50 companies in this country could eventually use electronic computers. Instead, by mid-1958, over 1200 companies, plus governmental agencies and the armed forces, have installed 1700. At least 3000 more are on order at prices from $300,000 to $2 million each. Dozens of companies are putting in a second or third computer. Problems that might, with pencils and slide rules, have taken a hundred men a hundred years to solve, and therefore were never undertaken, can be done through electronic computation in months or weeks.

OPERATIONS RESEARCH

Obviously, a major part of the formal training for modern engineers should be devoted to the field of operations research. This may include a discussion on mathematical simulation, on game theory, on linear programming, and on symbolic logic, with some specific examples. Two other subjects should also be considered to some extent. One is statistical quality control and reliability engineering. The other is statistical inference, in particular the scope and procedure of market research for engineering products. In the present day highly competitive industrial environment, market research can be of significant importance to every engineering production system.

Apart from giving the student the necessary background for the competitive aspects of modern industrial life, training in electronic computation and applied mathematics will offer him an immense self-confidence. Mathematics is also among the best means for promoting creativity in human beings. An organized effort to promote creativity is a relatively new force in our culture; up to now there has been little effort to encourage young men to use their imagination, and few teachers have made them conscious of what ideas are or how to go about having them.

CONCLUSION

One may question the wisdom of a distinct and separate systems engineering program by asking, "If systems engineering deals with the interaction of man-machine-environment and such interaction has gone on since the advent of man and tools, why is it considered a new concept?" Fundamentally, systems engineering is new only as a formal discipline. Just as the various branches of engineering developed from civil engineering when all non-military engineering could no longer be done by one group, systems engineering is now evolving as a separate and distinct art. In the age of atomic weapons, long-range missiles, and other great technological developments, reasoning based on marginal improvement over existing facilities is no longer valid. In developing automatic production facilities or automatic weapons, the entire process from start to finish must be engineered as a unit. In managing aggregations of economic might, like the modern corporation, analytic techniques have to be used where previously some casual insight might have been just enough. When this need became more prevalent, new approaches had to be found, which have now become distinct as a branch of engineering, cutting across the older engineering disciplines, called systems engineering.

A Control Procedure Applied to Subjective Evaluations

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IN INDUSTRY, many products are evaluated only by using the judgment of trained individuals. These persons make subjective decisions as to whether or not the product meets the required quality standards. In order to obtain accurate and consistent results over a period of time, some method of control must be maintained with respect to these evaluations. The purpose of this paper is to discuss a control system which will evaluate the inherent variability of decisions made by people.

To further illustrate the problem, consider an inspection scheme which involves sampling from each day's process and then evaluates the quality level of the sample. Since the decisions and the process quality may both change from day to day, it is obvious that it is difficult to distinguish between the two sources of variation. In fact, it may be impossible to tell whether both have changed or neither has changed. To overcome this variability of decision, which is not desirable and not necessarily random, it is necessary to use a control plan.

This paper presents a control procedure which separates the decision changes and process changes by comparing the evaluation results of the same items examined at two different time periods. This system provides a means of answering the two following important questions:

1. Have the decisions changed significantly? If so, which of the operators are making different decisions and in what way are the decisions different?
2. Has the process level changed significantly? If so, in what direction?

Results can then be used by supervision in determining whether operators need additional training or whether internal or external changes have affected the process.

CONTROL PROCEDURE

For this type of problem there are two aspects of control; namely, the method may be used to control only week to week changes or it may be employed to compare succeeding weeks against a base week. The difference is illustrated by the following two questions:

1. Have the decisions changed significantly from the preceding week?
2. Have the decisions changed significantly from the base week?

The answer to the former question is of little value as the two sources of variation may confound the week to week changes. That is to say, reported process averages would appear to be different only because the operators' decisions have changed. The following discussion answers the latter question (although it can be utilized to answer the former). This control procedure always makes reference to a base period in time and therefore eliminates the effect of the operators' decisions so that the process can be correctly assessed.

The actual control procedure is accomplished by recycling control items, that is, the same set of product items is viewed at two different times. These control items are randomly included within the batch of production items that the operators evaluate. The evaluation results on the control items are then used to determine process and operator decision changes with respect to the base week. Moreover, by correcting for operator decision changes in this data, one may obtain an approximation to the results that would have been received if, say, the second week's process had actually been evaluated during the base week.

The following three sections will discuss the general procedure of evaluating the operators' decisions, process variation and data correction. This will be followed by an example to illustrate the concepts.

GENERAL PROCEDURE

To develop the procedure, it is first necessary to consider two basic concepts:

1. Each item that is evaluated has an associated score.
2. A group of item scores constitutes a frequency distribution.

ITEM SCORE

The item score idea may be described by considering an infinite population of identically trained operators

looking at a particular item. (To simplify the discussion, let us call these operators inspectors, remembering that in reality they may be any operators who make a subjective evaluation concerning the quality of a product.) Each inspector is assumed to have had a considerable amount of training as to what constitutes a passable item (according to established customer standards). Since each inspector can pass or reject an item, the item score is defined as the ratio of total rejections to total decisions made by the population of inspectors; namely, the probability of rejecting an item. The better the item, the lower the score, and the poorer the item, the higher the score. Items, whose quality is questionable or borderline, will have scores centering around one half.

If P_i = probability of rejecting an item, the better quality items will have $P_i \to .00$ and the poorer quality items will have $P_i \to 1.00$.

Since in real life we never have an infinite population of inspectors evaluating a process, but a finite population, only an estimate of P_i is available. These estimates are what we will be using.

FREQUENCY DISTRIBUTION

It is evident that each item will have its own score. Therefore, any batch of items may be assumed to have a distribution of item scores. For a sample of items that have been inspected and for a finite number of inspectors, a histogram may be plotted to illustrate graphically the results.

SELECTION OF THE CONTROL ITEMS

If only the inspectors' decisions are to be controlled and not the inspectors' decisions and process combined, the control items may be selected in any manner, that is, a random or biased sample from work coming to the inspection operation, a random or biased sample from passed items, etc. However, because of the necessity for the process control, the control items should be a random sample from the base week's production. In this way, the decisions made about the control items may be used in two ways with regard to the process quality:

1. As a measure of the product quality for the base week.
2. As the base scores used in the control procedure.

Control items then, are a random sample obtained from a week's work coming into the inspection operation and are all inspected during the initial week. At the end of the week, the entire set of control items is randomly divided into sub-samples. A different sub-sample is shown to the inspectors during each of the next weeks to obtain the second set of decisions. In this way, a comparison is always made to the base week. During the final week, while the last sub-sample is being shown, a new batch of control items is shown and the cycle is repeated. By this cross-over between samples, reference may always be made to the base week.

INSPECTOR COMPARISON

There are many comparisons that can be made: i.e. A. compare the same inspector's decisions for week No. 1 to his decisions for week No. 2; B. compare the decisions of all the inspectors for week No. 1 to an inspector's decisions for week No. 2. However, each of these comparisons is a special case of the general condition of comparing a number of inspectors for the first week to a later week. The following discussion is for the latter condition and is concerned with answering the question, "Is the observed disagreement more than that to be expected by chance?" The effect of chance must be considered as a source of variation as we are dealing with samples. Therefore, a comparison must be made on the basis of actual results versus expected results. The following procedure gives a means of determining the expected values and of making the comparison.

Let

n_1 = number of inspectors for the first week (or the base week).

P_{i1} = probability of the i-th item being rejected during the first week. i varies from 1 to N, the total sample size.

The probability of r_1 inspectors for the first week rejecting the item and $(n_1 - r_1)$ accepting it is then the binominal probability =

$$\frac{n_1!}{(n_1 - r_1)!r_1!} P_{i1}^{r_1}(1 - P_{i1})^{(n_1 - r_1)}$$

It has been assumed that each inspector in the base week has the same probability of rejecting a particular item, or that each inspector is evaluating the item in the same manner. At the second evaluation, the interest is in whether P_{i1} has remained the same (for all items). Or if P_{ij} = probability of the i-th item being rejected during the j-th week where $j > 1$, the question becomes, "Does $P_{i1} = P_{ij}$ for all i's?" It will be assumed that the answers given during any one week are independent of those for the next week. There is a slight chance an inspector may remember a particular item, but he will not remember his previous decision. This has been shown through the analysis of past data. Therefore, because of the independence, the probabilities for the two weeks may be multiplied together to obtain the joint probability.

Let

n_j = number of inspectors for the j-th week the items are shown $(j > 1)$

s_j = number of rejections for the n_j inspectors. s_j varies from 0 to n_j

If r_1 and s_j inspectors rejected the i-th item in the first and following weeks respectively, this probability is:

$$\frac{n_1!n_j!}{(n_1 - r_1)!r_1!(n_j - s_j)!s_j!} P_{i1}^{r_1}(1 - P_{i1})^{(n_1 - r_1)} P_{ij}^{s_j}(1 - P_{ij})^{(n_j - s_j)}$$

However, the hypothesis is that $P_i = P_{i1} = P_{ij}$ for all i's; therefore, the joint probability under this hypothesis is:

$$\frac{n_1!n_j!}{(n_1 - r_1)!r_1!(n_j - s_j)!s_j!} P_i^{r_1+s_j}(1 - P_i)^{(n_1-r_1)+(n_j-s_j)}$$

For $r_1 + s_j =$ constant (K), the formula for the joint probability may be rewritten as:

$$\frac{n_1!n_j!}{(n_1 - r_1)!r_1!(n_j - s_j)!s_j!} P_i^K(1 - P_i)^{n_1+n_j-K}$$

A conditional probability for $r_1 + s_j = K$ is determined as follows:

The sum of the joint probabilities is:

$$P(r_1 + s_j = K) = \sum_{r_1+s_j=K} \frac{n_1!n_j!}{(n_1 - r_1)!r_1!(n_j - s_j)!s_j!} P_i^K(1 - P_i)^{n_1+n_j-K}$$

Therefore, a conditional probability is:

$$P(r_1 = x \mid r_1 + s_j = K) = \frac{\dfrac{n_1!n_j!}{(n_1 - x)!x!(n_j - K \times x)!(K - x)!} P_i^K(1 - P_i)^{n_1+n_j-K}}{\displaystyle\sum_{r_1+s_j=K} \frac{n_1!n_j!}{(n_1 - r_1)!r_1!(n_j - s_j)!s_j!} P_i^K(1 - P_i)^{n_1+n_j-K}}$$

$$P(r_1 = x \mid r_1 + s_j = K = \frac{1}{(n_1 - x)!x!(n_j - K + x)!(K - x)! \displaystyle\sum_{r_1+s_j=K} \frac{1}{(n_1 - r_1)!r!(n_j - s_j)!s_j!}}$$

Therefore, a conditional probability is independent of i. This implies independence of the particular item and hence independence of the control items selected, a point that was mentioned previously.

As developed, only the elements that form a diagonal from lower left to upper right are considered (that is $r_1 + s_j = K$) when determining a given set of conditional probabilities. The elements for $r_1 = 0$, $s_j = 0$ and $r_1 = n_1$, $s_j = n_j$ are not considered, as the number of items for them is a function of the product quality. For a 2 inspector example with $j = 2$ and $n_1 = n_2$, the marginal and joint probabilities would be written as shown in Table 1.

The conditional probabilities for $r_1 + s_j = 2$ are:

$$P(r_1 = 0 \mid r_1 + s_j = 2) = 1/6 = .167$$
$$P(r_1 = 1 \mid r_1 + s_j = 2) = 4/6 = .666$$
$$P(r_1 = 2 \mid r_1 + s_j = 2) = 1/6 = .167$$

The expected control item frequencies can be determined as follows:

For a given week (j) let:

$X_{r_1s_j}$ = actual control item frequency for r_1 and s_j rejections

$P(r_1 = x \mid r_1 + s_j = K)$ = conditional probability for r_1 and s_j rejections

The expected control item frequencies for a given diagonal $(r_1 + s_j = K) =$

$$X'_{r_1s_j} = P(r_1 = x \mid r_1 + s_j = K) \sum_{r_1+s_j=K} X_{r_1s_j}$$

A χ^2 statistic is used to determine if the actual values are what might occur by chance alone. The formula for χ^2 is:

$$\chi^2 = \sum_{r_1+s_j=K} \frac{(X_{r_1s_j} - X'_{r_1s_j})^2}{X'_{r_1s_j}}$$

The null hypothesis is rejected if the observed differences are significant at a desired risk level. When making the test, the diagonals may be considered in part or in total. The degrees of freedom associated with the individual χ^2 for each diagonal equals the number of elements in the diagonal less one. The degrees of freedom associated with the χ^2 for all the diagonals equal the number of inspectors the first week times the number of inspectors the week the items are shown again ($d.f. = n_1n_j$).

At this point, mention should be made of the comparison of an individual inspector to the group. Such a comparison would be made by comparing one versus all of the inspectors and would tell which inspectors are indiscriminate, that is, on the average rejecting more of the good material and passing more of the poor material, knowing this is important for deciding which inspectors need additional training.

PROCESS COMPARISON

The measure of the process quality for the base week is obtained by the inspectors evaluating the control

TABLE 1

		Week No. 2 Number Rejections (s_2)		
		0	1	2
		$(1-P_i)^2$	$2P_i(1-P_i)$	P_i^2
Week No. 1 Number Rejections (r_1)	0	$(1-P_i)^2$	$(1-P_i)^4$	$2P_i(1-P_i)^3$	$P_i^2(1-P_i)^2$
	1	$2P_i(1-P_i)$	$2P_i(1-P_i)^3$	$4P_i^2(1-P_i)^2$	$2P_i^2(1-P_i)$
	2	P_i^2	$P_i^2(1-P_i)^2$	$2P_i^2(1-P_i)$	P_i^4

items. (The batch of control items is a random sample taken from the production items.)

For any other week, the process quality is measured by comparing the inspectors' decisions for the following two groups of items:

1. A random sample from the production items for the current week.
2. A random sub-sample of the base week's production items. (This is a re-evaluation of the control items.)

The decisions made on the aforementioned sample and sub-sample are compared by tabulating the data in a contingency table. A χ^2 statistic is used to evaluate the null hypothesis that the production items came from the same distribution as the control items. Any observed difference is due to sampling error or process differences. There is no inspector decision variability effect because the items from the two groups are evaluated simultaneously.

For s_j rejections

X_{s_j} = actual control item frequency
X'_{s_j} = expected control item frequency
Y_{s_j} = actual production item frequency
Y'_{s_j} = expected production item frequency

Therefore

$$\chi^2 = \sum_{s_j=0}^{n_j} \left[\frac{(X_{s_j} - X'_{s_j})^2}{X'_{s_j}} + \frac{(Y_{s_j} - Y'_{s_j})^2}{Y'_{s_j}} \right]$$

The degrees of freedom equal the number of inspectors ($d.f. = n_j$). The null hypothesis is rejected if the observed differences are significant at a desired risk level. The rejection of the hypothesis would mean that the process quality has changed significantly.

DATA CORRECTION

The final point is concerned with applying a correction to the latter week's production data to determine the results that would have been received had it been evaluated during the base week. Table 2 illustrates the four situations that may occur and shows whether or not a correction factor should be applied.

Obviously, if the inspectors' decisions have not changed significantly, it is unnecessary to make a correction. Also, if the inspectors' decisions have changed, but not the process, a correction is unnecessary, since the base week's production evaluated during the base week is sufficient. However, when both sources of variation have changed, a correction is needed.

TABLE 2

Has the process changed?

		Yes	No
Are the Inspectors' decisions different?	Yes	Correct	Don't Correct
	No	Don't Correct	Don't Correct

Essentially, the correction procedure assumes that the distribution of scores for the production items for the latter week is the same as the distribution of scores for the control items. For this reason, the results are only approximate and are not to be interpreted as derived from any rigorous mathematical treatment.

The procedure utilizes control item information to effect a transformation of the later week's production data. This is done by considering the differences of decisions that were made on the same control items for both of the two weeks.

For a given value of s_j, let:

$\sum_{r_1=0}^{n_1} X_{r_1 s_j}$ = total number of control items

Y_{s_j} = number of production items

$X_{r_1 s_j}$ = number of control items for an element

Then the estimated number of production items with s_j rejections that would have had r_1 rejections during the base week is equal to:

$$Y_{r_1 s_j} = \frac{X_{r_1 s_j} Y_{s_j}}{\sum_{r_1=0}^{n_1} X_{r_1 s_j}}$$

EXAMPLE

To illustrate the use of the above procedures, consider such a control scheme with respect to the evaluation of color print quality. In the production area, inspectors are stationed at the end of the production line to classify each item as either a pass or a reject (100% inspection). The amount of inspection time required is a function of the product quality. That is, as the process quality improves, the inspection time needed to make a correct decision becomes less. Therefore, in order to determine the correct amount of inspection needed it is necessary to continually know the true process quality (without any operator decision variability).

Because of this requirement and because supervision also desired to evaluate correctly the effect of changes in the process, the quality of the outgoing (passed) prints, and the decisions made by the inspectors, it was necessary to develop a control scheme. The previously described scheme was developed but, because it was not practical to randomly mix control prints in the work at the time the inspection was done, a reinspection procedure was used.

Samples from all the prints evaluated by each inspector are reclassified by reinspectors. These reinspectors are in theory the most accurate and reproducible measuring instruments because of their selection and training. For these reasons they are used as the measuring and controlling instruments for both the process quality and for the inspectors.

Control prints are produced during a regular produc-

tion week and are all inspected and reinspected during this week. The entire set of control prints is randomly divided into twelve sub-samples. A different sub-sample is shown to the reinspectors during each of the next twelve weeks to obtain the second set of decisions. During the 12th week while the last sub-sample is being shown, a new batch of control prints is shown and the cycle is repeated.

The print scores of the control prints are illustrated in the following chart for 3 reinspectors where a blank indicates a passed print and a 1 indicates a rejected print.

	Reinspector			
Print Number	*1*	*2*	*3*	*Score*
1	1			.33
2	1	1		.67
3				.00
4	1	1	1	1.00
↓				↓
N				etc.

The results of such an evaluation would form a histogram as shown in Figure 1. It has proven desirous for discussion purposes to consider prints with a score of 0

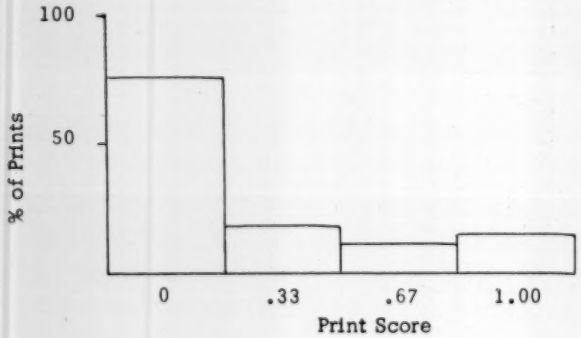

Fig. 1

or .33 as good prints, .67 as fair prints and 1.00 as poor prints. The cells of the histogram are for these respective categories.

To illustrate how to use the procedure, consider the following simplified data. These data are arbitrary and do not represent actual conditions.

REINSPECTOR COMPARISON

Let

$j = 2$ (Second week)
$n_1 = n_j = 1$ reinspector
$N = 1100$ control prints

Table 3 illustrates the reinspector's evaluation of the 1100 control prints. A score of 0 represents passed prints and a score of 1 represents rejected prints.

The table shows that some disagreement occurred but it must be determined if this was due to chance. For this example, there are only two frequencies that can be evaluated and these lie on the diagonal for $r_1 + s_2 = 1$.

TABLE 3
Week No. 2
(s_2)

		0	1	Total
Week No. 1	0	950	50	1,000
(r_1)	1	25	75	100
	Total	975	125	1,100

The conditional probabilities are:

$$P(r_1 = 0 \mid r_1 + s_2 = 1) = .5$$
$$P(r_1 = 1 \mid r_1 + s_2 = 1) = .5$$

The expected control print frequencies for the diagonal $r_1 + s_2 = 1$ are:

$$X'_{0,1_2} = .5(25 + 50) = 37.5$$
$$X'_{1,0_2} = .5(25 + 50) = 37.5$$

These figures give a χ^2 value of 8.34. Since this is greater than the χ^2 value of 3.84 for 1 degree of freedom at the 5% risk level, the null hypothesis can be rejected. It may be inferred that the reinspector is evaluating the prints differently in week No. 2 than in week No. 1.

PROCESS COMPARISON

For the second week, the reinspector evaluated for the first time 1,000 production prints and of these passed 800. The hypothesis is that these prints came from the same distribution as the 1,100 control prints re-evaluated in week No. 2. The actual and expected frequencies are listed in Table 4.

The expected frequencies were obtained from calculations similar to those made to obtain the X'_{s_2} frequency.

$$X'_{0_2} = \frac{(X_{0_2} + Y_{0_2}) \sum_{s_2=0}^{1} X_{s_2}}{\sum_{s_2=0}^{1} (X_{s_2} + Y_{s_2})} = \frac{1775}{2100} \times 1100 = 930 \text{ prints}$$

In this case $\chi^2 = 29.55$, with one degree of freedom, is significant at the 5% level. Thus, it may be inferred that the process has changed significantly from week No. 1 to week No. 2.

TABLE 4
Week No. 2
(s_2)

		0	1	Total
Control Prints	X_{s_2}	975	125	1,100
	X'_{s_2}	(930)	(170)	
Production Prints	Y_{s_2}	800	200	1,000
	Y'_{s_2}	(845)	(155)	
		1,775	325	2,100

DATA CORRECTION

Because both the reinspector and process have changed, it is necessary to apply a correction to the second week's production data.

For an example calculation, consider the determination of $Y_{0_1 0_2}$, the number of production prints that would have been passed if they had been evaluated during the first or base week.

$$Y_{0_1 0_2} = \frac{(X_{0_1 0_2})(Y_{0_2})}{\sum_{r_1=0}^{n1} X_{r_1 0_2}} = \frac{950 \times 800}{975} = 780 \text{ prints}$$

Table 5 gives the results of the other calculations for $Y_{r_1 r_2}$.

This implies that a total of 140 prints would have been rejected in the base week, and a total of 860 prints would have been accepted, a waste factor of 14% as compared to one of 20% in the original data. The change shows that a decision to take any corrective action on the process should not be made until an accurate analysis of the process has been obtained.

There is another comparison that is made with respect to the color print quality evaluation. That is in regard to the decisions that are made by the inspectors. The quality of their decisions is determined by comparing, for the same prints, an inspector's decisions to the reinspector's decisions. This is done in the same way that the reinspector's decisions are compared within themselves. The only difference is that decisions made on production prints are used for comparison purposes rather than control prints.

TABLE 5

		Week No. 2 (s_2) 0	1	Total
Week No. 1	0	780	80	860
(r_1)	1	20	120	140
	Total	800	200	1,000

CONCLUSION

The discussion to this point has implied action being taken on any statistically significant difference. In actual practice a statistical difference should be the basis for action only if the difference is of practical importance. Management must decide what changes in the process quality and decisions have economic implications. Knowing what is important, the engineer should set up the procedure so as to detect both trend and practical differences. These considerations are, of course, a function of sample size. For a product of good quality a larger sample must be taken since the proportion of bad or borderline prints is small. In the case of the control system described, 1,500 control prints viewed each week gave adequate information about the measuring instrument.

This procedure may be adapted to any process where consistent and accurate data must be obtained. Consistency and accuracy of the data are prerequisites for sound decisions. This paper has shown one method of obtaining data of this type where the measurement is based on subjective judgment and hence a major source of variability.

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How to Measure and Appraise Your Industrial Engineering Department Performance*

by THOMAS E. KELLY

Manager, Methods and Standards Department, The Atlantic Refining Company

IN CONSIDERING how to address myself to the topic assigned me I came to two early conclusions:

First, that it would be only fair to mention at the outset that I know of no practical basis for completely separating individual from departmental performance, since in such a staff department, people *are* the department.

Second, I concluded that in any treatment of the subject it would be necessary to reflect upon some basic management concepts and techniques most of which you and I have known about for years.

I can just hear one of you saying, "If your first two conclusions are you don't see how you can stick to the subject, and you believe you must talk to us about management concepts and techniques that we already know about, then let's both save time and call it off right now."

That might not be a bad suggestion; however, I do contemplate doing something more constructive, but it needs your help and a promise. As we reflect upon these basic management concepts and techniques, will you ask yourself—*not* whether we know about them, but, instead, ask, as I have done—what kind of job has my department done in applying them so that each is functioning in its proper relationship to produce good departmental performance?

I would like to repeat this point, if I may, because I don't want anyone saying all I did was mention some concepts and techniques which any good Industrial Engineer should know. The challenge lies in our ability to be objective in answering the question, "What kind of job has the department done in applying these concepts and principles so that each is functioning in its proper relationship to produce good departmental performance?"

As you do, check off a (−), (+), or "average."

After having worked for a period of over 30 years in a line capacity as general superintendent of a metal manufacturing company and in a staff capacity as an Industrial Engineer, as Assistant Personnel Manager for a large corporation, and in more recent years as a Department Manager of the Methods and Standards Department of The Atlantic Refining Company, I believe I have come to appreciate at least some of the things needed for good departmental performance, but I am still learning. I learned that it's not good to expect every other department to do something about applying management engineering, but in your own Industrial Engineering department to assume that just knowing or being so-called experts in these things takes care of the situation.

A STANDARD FOR THE DEPARTMENT

I believe it is reasonable to say that we cannot measure or appraise without some standard, whether it be a mental concept, verbal description, a numerical goal, or some combination of these, against which to compare actual performance. For a departmental standard the first requirement is to describe the over-all function and job to be done. A manager of a department must be able to describe the job he is setting out to do or no one, including himself, will ever know what to do, much less, how well he did it. This applies to the department as a whole and to every section and individual within the department.

THE KIND OF DEPARTMENT

It is appropriate, therefore, that in considering the subject we develop a clear concept of the kind of department about which we are talking. Unfortunately, the term "Industrial Engineering" has a widely differing meaning in different companies, and even to individuals within the same company.

So that you and I may be on the same wave length as we each consider the subject, let's thing of an Industrial Engineering department as one with Industrial Engineering defined as it was by the American Institute of Industrial Engineers in October of 1955. While the department may be called a Methods and Standards Department, Organization and Methods, a Management Engineering Services Department, or an Industrial Engineering Department, this is not a point for discussion. A Committee of approximately 20 individuals, representing the coun-

* Based upon a presentation to an American Management Association Seminar, October 1, 1958.

try's leading engineering departments, management consulting firms, and educators in the field, developed this definition of Industrial Engineering:

> Industrial Engineering is concerned with the design, improvement, and installation of *integrated systems* of men, materials, and equipment. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

Within this broad definition let's assume the department's functions have been carefully described to suit a particular company and they include a number of specific activities. For example, the Methods and Standards Department of The Atlantic Refining Company, a central staff unit of approximately 100 persons, directly serves all other operating and staff departments of the Company, and also performs certain control functions and services for the corporate management as a whole.

Without burdening you with detailed listings and full descriptions of assigned responsibilities, perhaps just a mention of the major areas will suffice to typify the kind of department about which my comments are being addressed. While each company will organize differently and can interpret my comments to suit, I am thinking of my own department which:

1. *Conducts methods studies* and aids in installation aimed at improving the application of human effort to methods and to the operation of facilities. Such studies or installations may be made in the Manufacturing, Marketing, Producing and Transportation Departments, as well as in any of the company's staff departments, as a result of approved proposals or operating management requests. These studies range from detailed operations analysis, with resulting standard practice instructions or procedures, to broad methods and systems studies involving organizational arrangements of departmental and interdepartmental nature. Some lend themselves to the application of the so-called operations research approach and utilize advanced mathematics and computers. Many of the studies are directed toward analysis of office equipment and the mechanization of clerical or technical computational work, use of electronic data processing equipment and data transmission devices.
2. I'm thinking of a department that *develops performance standards* and designs the associated application and control plans for planning and measurement of worker and supervisory operating performance. These plans may include standards for wage incentive plans such as for salesmen, clerical workers, or packaging hourly workers, or they may be plans integrated with a standard cost and budgeting system or a production control system.
3. This department is responsible for *providing certain related management advisory and control services.* This would include such things as exercising a company's "paperwork forms" control function, and performing a technical audit on all requisitions for office equipment, computers, office furniture, air conditioning equipment, or office space. It would include the furnishing of assistance on company committees and in drafting company policies or procedures related to this department's area of interest.

WORK OF DEPARTMENT

A careful examination of these functions reveals that the work of a department of this type generally falls into two main categories:

1. Work that has an expected measurable dollar benefit.
2. Work designed to facilitate management's decisions, operating techniques and controls where the benefits do not lend themselves to quantitative measurement.

THE ENGINEER'S APPROACH

So at the very outset we recognize that any measuring or appraising of your department must be based upon something more than just those activities which happen to produce the kind of benefits which can be calculated in dollars.

This brings us back to the basic question—how to measure and appraise such a department.

Industrial Engineering, like many other professions, must be evaluated not only on quantitative factors, which show up in the end product of the department, but to a larger extent upon qualitative factors. I am sure I will not surprise you when I say that I do not know of any basis for absolute measurement of these qualitative factors, which are so important to a department's accomplishments. It is in keeping with the engineer's approach, however, to conclude that if we can't measure the end product, perhaps we can measure and effectively appraise some of the selected activities which experience has proven will lead to the creation of good results. Working backwards on the problems, we know that assurance of maximum accomplishment can only come through assurance that there are good facilities, leadership, planning, and administration. Following this approach, I suggest that we consider five basic questions which, if answered objectively, should help us find a solution to the over-all evaluation problem.

Again, may I remind you that the management concepts and principles referred to are not new, but, unfortunately, the application and check-up on their contribution to departmental performance is new to too many Industrial Engineering departments.

ARE EFFORTS POINTED IN THE BEST DIRECTION?

While we may be handicapped in our ability to measure the quantity and quality of service actually rendered by a department, we know that in some respects the department is like a ship at sea. If you point it toward the desired destination, you may have some troubles along the voyage, but you will at least have an excellent chance of reaching your desired destination.

POINTED THROUGH ORGANIZATION, POLICIES AND PROCEDURES

As I mentioned in my opening comments, the department can't even approach having a standard of performance or a means of evaluating its efforts unless everyone concerned knows exactly what the job is that both he and the department are trying to accomplish.

For the Industrial Engineering department to function at its best, it should *operate within an orderly company*

framework of organization structure, policies and procedures. The department should operate within a clear company-wide policy outlining "operating—staff" relationships wherein it specifies who has the right of final decisions and how differences may be resolved. The department needs for its best performance *good communications channels within the company* both through committees and line organizations, and, finally, the *Industrial Engineering department itself needs to have its over-all functions clearly established with top management endorsement and sincere active support.*

To perform at its best, the Industrial Engineering department needs its departmental functions detailed along with individual definitions of responsibility so that each person knows his limits of authority, his assigned responsibility, and his channels of communication. In this manner we have greater assurance that, not only each individual, but the department as a whole, is pointing its efforts in the right direction. To be an effective department we should look for the establishment of basic departmental policies and procedures to further aid in the pointing of efforts and avoidance of wasted energy through repeatedly having to reconsider common problems. A department without all these conditions of organization, policies and procedures, cannot give its best performance. An evaluation of these conditions may, therefore, be made to determine the facts without regard as to why the conditions are as they are. I suggest you look for these things and score your department accordingly.

ATTITUDES POINTED CORRECTLY

Ask yourself, or discuss with others, whether the attitudes within your department are pointed correctly.

1. Are the attitudes concerned more with building departmental, divisional, sectional or group empires, or are the attitudes as they should be constantly pointed, on an undiluted basis, toward the good of the company?
2. Are there a goodly number of persons in your department who are really enthusiastic and dedicated to their profession? It is easy to sense the difference in departmental drive when its "got religion" to keep it going in the right direction.
3. Are the personalities and mannerisms pointed toward building up friendly relationships with the departments to be served, and is this being done on the basis of objectivity and integrity? I know of few other professions where the strain on objectivity and integrity is any greater. You know the old adage, "Figures don't lie, but . . . " and the temptations are great at times for Industrial Engineers to rationalize desired conclusions. One of the real tests of a department's "bigness" is its ability to admit its mistakes and profit by them. Without a pointing of these various attitude ingredients in the right direction there can be little hope of a continuing, high-level, departmental performance. By reflecting upon these items and determining if there is a need for improvement we have another basis of scoring departmental performance.
4. Finally, are the attitudes of managers whom you wish to serve pointed in the same direction as your department? Has your department done a good job of seeing that Industrial Engineering is understood and that your company makes it clear that for an operating manager to seek Industrial Engineering help is not a sign of weakness, but a sign of alertness and resourcefulness.

POINTING OF OBJECTIVES AND BASIC PLANS

For good performance, we need evidence that the department is being given direction through establishment of the best over-all broad programs, objectives, and basic plans; and that these broad plans become the basis for the department's specific projects. All creative engineers can produce more ideas for things they would like to do than can be supported by available money or staff. Also, engineers are human and tend to yield to the temptation of riding their pet projects, serving the client who is most demanding, forgetting maintenance to do more sensational things or doing things which come naturally without causing headaches. Unless there is evidence of sound planning and a pointing of the department's over-all efforts to the best major areas of emphasis, even the finest execution on the part of subordinates will leave the department falling short in its over-all performance. To be effective the plans should allow for the benefit of reactions from the company's top officers and the managers from within the departments to be served. So in your appraisal, I suggest that you examine the extent to which your department lays out this broad planning program to insure optimum benefits from available supervisory resources.

POINTED WITH LEADERSHIP IN FIELD OF ASSIGNED FUNCTIONS

The department's efforts should be in the direction of showing leadership to company management in the field of the department's assigned functions.

Your department as a team of individuals is expected, not only to be creative, but to be resourceful. Among other things it must bring ideas from outside the company and serve as a catalyst in making them applicable. It must help management to be alert to possibilities of better methods or techniques. The department's promotional efforts should be with a good sense of timing so as not to dissipate energy by being premature, or fail the company by being too late with the munitions for meeting competition. We would note, too, that while we are expected to provide this type of leadership, we are also expected to see that our personal desires and newly founded convictions do not blind us to the needs as seen by experienced individuals in the company departments served. With due regard for satisfying of needs, and of letting the other fellow get the credit for your idea, I suggest you evaluate your department by asking yourself if most of the proposals leading to the department's work really originated in the Industrial Engineering department, or within the departments served. For example, who first promoted and developed the use of business data computers in your company? Or, who in your company initiated work measurement for clerical or indirect labor operations, when

usually measurement is only thought of in connection with non-clerical and routine factory type operations? Or, for example, who first proposed tackling a difficult management problem by the use of the so-called Operations Research techniques?

Perhaps another question of a more basic nature having to do with leadership should be asked. Should you evaluate your departmental performance in terms of how well it points its efforts toward satisfying your company's needs, or on how well it performs on only that portion of the total job that it is permitted to do? I suggest you pause, as I did, before answering this.

The first inclination is for all members of the department to disclaim responsibility for anything that is not specifically spelled out in their assigned responsibilities, or that calls for manpower and money beyond the limits of the approved and subdivided departmental budget. Before reaching a conclusion, however, consider what some of the reasons might be that would cause management to limit the funds and personal support of your department. You may find your department is more responsible for this situation than those individuals or things which you considered as obstacles beyond your control.

1. I suggest you ask yourself if your department has performed well enough on what it has done to warrant more support? If the answer is negative, then you know what your departmental score is and that your department is not being pointed in the direction to warrant further growth.
2. If your department has performed well on what it did, but has scope and budget restrictions, have you or members of your staff made a case to demonstrate this and accompanied it with a specific and well supported proposal for removal of the restrictions? Again, if the answer is in the negative, then you can't absolve your department, and you have another clue as to whether your department's efforts are being well pointed.

I have been discussing how to evaluate whether your department's efforts are being pointed in the best direction and my reason for this is that I believe so very much depends upon getting a good aim before you fire at the target. My last comment on scope and budget restrictions leads me to the second question regarding our overall evaluation problem.

IS THE INDUSTRIAL ENGINEERING DEPARTMENT PROVIDING MOST APPROPRIATE SERVICE?

You will probably agree that the amount of Industrial Engineering services rendered by a department as a whole is of direct concern in an evaluation of a department's performance. Performance is not at its best if too little or too much is supplied. Before any attempt at evaluation of the department's performance in this respect, it appears logical that we sharpen our thoughts as to what amount of service is most appropriate for our individual companies and for an Industrial Engineering staff within the company. Assuming that the department is operating efficiently in all other respects any attempt to answer these questions is complicated by the need to consider a number of things:

1. What is the optimum amount of service to help your company have better tools and methods for analyzing, planning, directing and controlling the utilization of human effort than your competitors have?
2. The answer as to amount, varies with the *character of a company's business*. It varies with such things as size, physical facilities, geographical layout, cyclical and speculative aspects and type of management and personnel requirements. For example, the automotive, clothing, toy, power company and petroleum companies all have widely differing basic needs and while they all need Industrial Engineering services of some type, the specific needs for any one technique or approach varies widely from "no need" to "full implementation."
3. The amount required for any company varies with the *unsatisfied needs* which exist at the particular period of the company's history. Certainly a company that has kept up to date in management techniques may not have the same needs as one that has not. Also, a company in a highly competitive industry faces a continuing need that may far exceed that of one in a less aggressive industry.
4. The determination of the optimum amount is further complicated by a consideration of the rate at which a company can assimilate the changes which accompany any Industrial Engineering program.
5. Consideration is given to the amount of work that can best be proportioned between an Industrial Engineering staff, other company personnel which could be specially trained, and perhaps an outside consulting firm, in order to determine how large the department should be to have a good portion of it with long-term stability. The larger the company and the older the department, the greater is the opportunity for a group of experts and a stabilized department, because of averaging out peak demands.

There are probably other things to consider but already we see enough to place us in a dilemma as to how much service to expect for the Industrial Engineering Department's performance.

ATTEMPT AT SOLUTION

Again assuming a department efficient in all other respects, and this is a big assumption, one attempted solution has been to identify the basic management tools or methods falling within the Industrial Engineering concepts, that are generally considered an acceptable minimum necessary for a well-managed company. With this approach estimates can be made of what your company has and what it still needs. For example, does your company have such things as performance standards, standard methods procedures, or mechanization of clerical activities, and with coverage to the extent it should have? Does your company have need for certain control functions, and if so what are they and what are the estimates for staffing to administer them?

This type of estimating to determine what is needed to meet certain ideals is unfortunately very incomplete since for one thing it only relates to the more conventional type methods and systems services. It would not, for example, allow for studies such as how to minimize in-

ventories or how to design a truck distribution and storage system for minimum operating costs or maximum delivery service, or how to lay out an office building for best utilization of space. This approach through examining of ideal minimum needs for service has its usefulness in tackling the problem, but it does not provide the complete answer as to how much service is appropriate for a given period of time. There have also been some attempts at trying to determine the types of work and size of staff required by seeing what other companies are doing. I can assure you that this can only be a very rough indicator to augment other information and it seldom, if ever, bears any relationship to your company's problems and readiness for such services.

ONLY SOUND APPROACH SO FAR

I submit therefore that after making a modest beginning with an Industrial Engineering staff, the only sound approach to finding the appropriate amount of Industrial Engineering services is to do so on a planned basis of trial expansion and a period of consolidation, appraisal and adjustment after each trial. The best answer evolves after a period of years following a record of some failures, profits from failures, and finally, a predominance of successful ventures.

ONE SUGGESTION FOR CONTROL ON AMOUNT

As one suggestion for controlling and evaluating the department's performance may I outline an arrangement we have been experimenting with at Atlantic. In Atlantic we have a policy that all staff departments have their costs charged wherever feasible to the various operating departments in proportion to service rendered, and when this is not feasible, then costs are carried as a company overhead. The "charge-out" is in support of the principle that the operating departments utilize these services and, therefore, are in a position to effect at least some degree of control over the expense. Through an analysis of our departmental functions and activities, it was possible to separate those which were either a service to the corporate management or for internal administration of the department from those which were directly chargeable to specific departments served. We found that this analysis provided groupings of work projects or assignments which could each be analyzed in detail in the light of the specific service required. All items except those which were done directly for specific departments were carried in an overhead account with suitable administrative controls. In this overhead account there was also provision for funds to conduct preliminary surveys so that the opportunity could be provided to search out and consider proposals for desirable studies.

In the case of the Methods and Standards Department in Atlantic, these overhead items represent the small portion of its total department expenses. The large portion is distributed through charges to departments utilizing the services in proportion to use. Other than activities related to company controls over office equipment and forms, departments serviced are free to request, accept, or reject, the use of these services just as thy would be with an outside consultant. They are not, however, permitted to establish independent and duplicating staffs, and the departments serviced are encouraged by the President to seek out the best use of Methods and Standards' services.

One of the results of this arrangement has been to force out the best quality of staff service because the staff department is always competing for a share of the operating department's expense budget in order to have an income for the operation of its own department.

Under such a competitive arrangement, operating departments are not inclined to approve the acceptance of charges unless they have pretty good assurance that the return on the investment in services will be sufficiently rewarding to forego other uses of available company money. This process is a practical leveling factor on the promotional efforts of a department, such as Industrial Engineering, and it helps in determining the optimum amount of Industrial Engineering services. I would not imply, however, that this process would operate to the company's best interests if it did not have, as we have in Atlantic, the advantage of top management personnel enlightened regarding the advantages and use of such services. Also, it requires for its success a high degree of integrity on the part of both operating and staff personnel. This is needed to insure that *important* differences in viewpoint on the solution to problems do not result in:

1. The staff department becoming spineless in its opposition because of a fear that it may lose favor with the operating department and fail to secure approval of its budgeted income, or
2. The operating department arbitrarily cutting off staff department income as a way of avoiding issues.

ONE INDICATOR OF DEPARTMENTAL PERFORMANCE

We believe that there is one indicator of good departmental performance when important differences are satisfactorily resolved and when, after trial expansion, predominance of successful ventures, and a leveling out of staff size, the department continues to receive a full work load of requests and authorizations for project studies from the president and the other line and staff operating managers. The department's growth under these conditions is then in keeping with its ability to earn its own operating expense plus an added attractive return to the company.

You will notice that I have referred to the appropriate amount of services rather than size of staff, since I believe that, once we have determined the former, then through administrative controls and records for estimating purposes, we can with reasonable accuracy convert the service needs into manpower required. This now brings me to the third question of the over-all evaluation problem.

IS THERE EVIDENCE OF GOOD TECHNICAL ABILITY AND COMPETENT PERFORMANCE?

I recommend that we augment our examination of a department's products with an examination of the facilities with which it has to work. Again, on the basis that if we can assure ourselves that the facilities, leadership, planning and administration are good, there is an excellent probability that departmental accomplishment will be good.

A keystone in this arch, of course, is the technical ability and competence of the department's personnel. While it is not appropriate to divert in this presentation to a detailed discussion of this personnel problem, I would suggest that the appraisal be made.

1. As to whether the personnel are equipped with suitable education, experience and personality.
2. As to whether there is a proper balance in the make-up of the personnel between engineering and salesmanship, both in oral and written expression, and between theory and practical experience. We should look not only for a blending of these qualities within certain individuals but also for a balance between individuals in order to establish a well-rounded and practical departmental staff.

I would suggest, too, that we not overlook indications that can come from an objective audit applicable to certain classes of Industrial Engineering activity and from formal personnel evaluation and development programs.

Finally, one excellent indicator of individual competence is the use that is made of work done and the volume of work the individuals produce.

This brings me to a fourth phase of the evaluation problem.

IS THERE EVIDENCE OF ADEQUATE FACILITIES AND ADMINISTRATIVE CONTROLS?

I will discuss first departmental and project controls and Industrial Engineering accountability.

For good performance we need assurance that there is at the departmental level a budgetary control system which limits expenditures and which provides the basis for accountability of performance against such limits.

You will recall that we spoke of an attempt to evaluate whether the department's efforts were being pointed in the best direction. In this connection we suggested an examination of the department's over-all objectives and basic plans for the division of its over-all effort. Springing from this broad planning for departmental direction we should see evidence of a breakdown and tie-in of these plans into assigned responsibilities for subdivisions or sections, and on down to the specific assignments to individual project engineers. We should see evidence of some coordinated paperwork to insure that all the pieces fit together with no overruns in expenditures, either on individual projects or accumulated charges as agreed to with the departments served. Project estimates frequently have to be revised as the projects develop due to new data or changes in decisions, scheduling and uncontrollable events. Additionally, the work load and skill requirements on any given project often vary as the various phases of a project are encountered, and the system must be able to quickly signal the need for revised assignments to permit the best utilization of the staff.

I saw my own department some years ago operating under loose controls, and I have seen the tremendous advantage that has come from our present internal control system. Through this system, we believe we have turned out much more work with fewer people. We also have established records on the cost of doing work so that estimates for budgeting engineering time have become quite reliable, and on certain classes of work could be considered in the category of standards for Industrial Engineering performance.

If there is evidence that the department has a good paperwork project control system, with associated time and record keeping, and that the system also aids in making rapid adjustments for balancing workloads with available staff personnel and skill, you can be assured that one major phase of departmental performance is at a high economic level.

PERIODIC CHECK-UP

Some products of Industrial Engineering effort can be worse than none at all if done poorly. This is especially true in the development of performance standards. We find that Industrial Engineering departments need a physical check-up at periodic intervals just like human beings, if they want assurance of continued top performance. Among these check-up devices are auditing procedures for sampling the quality of standards development, the quality of maintenance of installations, and the quality of report writing.

It would take considerable time to discuss some of the techniques utilized in these types of sample auditing, but for an engineering effort of any size the provision of sample auditing is necessary to the maintenance of good performance.

At reasonable intervals a department should benefit by reactions from managers serviced and from outside visitors. Also it should benefit from its members comparing what they do with what they see other companies doing when they visit with representatives of other companies.

Where these various audits are made on a practical basis, they provide another indicator of good departmental performance.

PROVISION OF RESEARCH AND REFERENCE FACILITIES

One should look also for the provision of a reasonable amount of research and reference facilities to support the engineering staff. As by-products of these research efforts, you should be able to set standard practice instructions and policies for the guidance of employees. However, the fertility of any department is dependent to a large extent upon the opportunity afforded each of its members for

exposure to experiences of others and to opportunities for interchange of thoughts with others engaged in the art and science. For example, I just can't imagine an Industrial Engineering department with a high performance rating that did not gain that rating with the help afforded by participation in professional organizations.

Once again, may I repeat that we can be reasonably sure of one area of the department's performance by examining the degree to which it equips itself with the necessary facilities and controls to increase the "probability" of good performance.

ARE THE DEPARTMENT'S PLANS AND EFFORTS RESULTING IN SIGNIFICANT BENEFITS?

In the preceding questions, we attempted to test the probability of good departmental performance. This approach was especially appropriate in view of our acknowledgment that one category of Industrial Engineering work results in benefits which cannot be calculated on a quantitative basis. The real test, however, is to determine if the department is improving the profit position of the company. If it is not, then there is no justification whatsoever for having such a department.

On work resulting in benefits which cannot be calculated on a quantitative basis, we depend almost exclusively upon the objective judgment of top management and the reactions of departments served to determine whether the work is worth while. This is the customary means for evaluating this portion of Industrial Engineering service, or, for that matter, the services of most other staff departments.

Let us consider further, however, the Industrial Engineering work that is expected to result in measurable dollar benefits.

DEFINITION OF MEASURABLE BENEFITS

Measurable benefits may be loosely defined as dollar values which can be assigned to the operating cost reductions and other operating benefits attainable by the operating department if and when they accept and install an Industrial Engineering proposal.

NOTES OF CAUTION IN CALCULATING BENEFITS

A separate paper could easily be devoted to discussing the subject of how to compute in monetary terms savings or other benefits. While I firmly believe that, wherever possible, we should try to estimate in a tangible fashion the expected benefits, I would warn against unnecessary dissipation of energy in trying to make exact, what at best can often be only an-order-of-magnitude estimate. The potential return on most Industrial Engineering work should be so pronounced that its approval would not need to waver on minor factors in a computation method. It is when an Industrial Engineer tries to detract from credit due the operating department that he usually gets pushed into quibbling over unimportant factors. We can't afford to forget that the operating departments are entitled to credit where they assume responsibility for installations and they perform the necessary actions to make the claimed benefits a reality. And, certainly, who should try to say how much of the benefits are attributable to the employees affected, the supervisor, the Industrial Engineer who may have created the proposal with help from others, or to the operating manager who may have had the vision and courage to arrange for the Industrial Engineer to make the required study and without whose help the proposal could never be converted to a benefit?

EVENTS LEADING TO CALCULATION OF BENEFITS

Let us consider events leading to the calculation of benefits. A good engineering approach to selling operating management on a proposal is usually preceded by a preliminary survey, which generally results in an estimate of the time and cost involved to make a thorough study and a rough estimate with some recognized speculation as to possible benefits from investing in such a study. Then, if the prospects are promising enough, a study is authorized which results in more specific recommendations for management action, with a fairly reliable estimate of the possible benefits to be anticipated. At this point all interested parties should carefully appraise the whole proposition, including the factors involved in the estimate of the benefits. A significant thing, which I would ask you to remember, is that at this point the money for the study has already been spent.

Also, at this point responsibility usually rests with the operating department to finally evaluate the practicality and operating advantages of such proposal, and then either accept complete responsibility for the required action, reject the proposal, or modify the proposal and benefits. It is apparent, therefore, that acceptance under these conditions implies a verification of the measurable benefits as computed. In the subsequent installation, the operating department may vary the proposal in certain respects and thus produce greater or lesser benefits than originally calculated and again accept responsibility for such variation.

It appears 1. that a valid basis for evaluating the benefits of Industrial Engineering effort occurs at the time that the Industrial Engineering department presents its final proposal to the operating department for taking some operating course of action, even though the department cannot claim the creation of the actual savings, and 2. that subsequent variation, either in course of action taken or the benefits to be attained, is basically a responsibility of the operating department.

CALCULATION AT TIME PROPOSAL IS MADE

As stated before, the ideal time for calculating benefits is at the time a proposal is made to the operating department. Such a statement of measurable benefits has two basic purposes:

1. It aids in selling the operating department on acceptance of a proposal.
2. Such a statement of measurable benefits can later be used by the Industrial Engineering department management in evaluating the performance of the department. The fact that it is an estimated benefit and the Industrial Engineering department was only one of the contributors, does not prevent its use in evaluation. The department can be evaluated on the importance of its accepted recommendations.

CALCULATION AFTER PROPOSAL IS ACCEPTED AND IN OPERATION

Even though an installation of an Industrial Engineering proposal has been made and the money spent for it, there are occasions when it is desirable to re-evaluate benefits in view of other major changes affecting the area involved. Under these circumstances there is much merit to considering the operating department responsible for determining actual benefits, with the Industrial Engineering department providing data and technical advice as required. On any other basis it is quite likely that the Industrial Engineer will find himself in the middle of a controversy from which very little good will come.

WHEN PROPOSALS ARE NOT ACCEPTED

As stated previously, when a proposal is made to an operating department it may elect *not* to accept such a proposal. One reason could be that the proposal, while well done, required an investment in time and money which could *not* be made in view of other demands for available company resources.

There are sometimes other reasons, however, which can have valuable appraisal indications for the Industrial Engineering department management. They may indicate any of the following significant conditions in the department:

1. A lack of practical skill in formulating the proposal.
2. A lack of selling or presentation skill.
3. A lack of confidence by the operating department resulting from previous performance or lack of performance by the Industrial Engineering department.

Under these latter circumstances the calculation of measurable benefits should not be used in any way to help justify the Industrial Engineering department.

METHOD OF CALCULATING BENEFITS

As I mentioned previously, a statement of measurable benefits given to an operating department as a part of a proposal serves two essential purposes:

1. It aids in selling the operating department on acceptance of a proposal.
2. It can later be used by Industrial Engineering department management for evaluating performance of the department.

In performing these two services it is highly desirable that all such computations be made in a uniform agreed-upon manner. This will eliminate many discussions as to the proper method of calculation each time a new proposal is made to an operating department. When used later for departmental appraisal purposes, it is again advisable to have had all computations made on a standard basis.

Whatever computational method is used, it should follow sound accounting principles accepted by your own company management. Under one method, which has gained considerable acceptance, the computation works out to a *total dollars annual benefit*. This is the net result of the operating costs to install, operate or act upon the proposal on the one hand, and the benefits resulting from it on the other.

You may recall that I asked you to remember that when the final proposal is submitted for a decision to act upon it, the money for the development study has already been spent. Therefore, the operating department at this point is only concerned with the total dollars of annual benefit if they accept and act upon the proposal, and the development cost, while chargeable to the operating department as an overhead item, is not an operating cost nor is it something which a decision could now influence.

RATE OF RETURN ON STUDY COST

Project development costs, however, are of substantial interest to the Industrial Engineering department management since they provide a reliable basis for controlling department costs and evaluating the results of development studies. To use this evaluation technique it seems desirable to compute where possible for each accepted proposal a "Rate of Return" on the study cost. Rate of Return may be defined as the annual rate at which development costs are recovered through operating benefits. It may be simply computed by dividing the total dollars annual benefit by the Industrial Engineering development cost.

The accumulation of project development costs and total dollars annual benefits should not imply, as I mentioned before, that it represents benefits made solely by the Industrial Engineering department. It is, however, a very realistic indicator as to whether one category of Industrial Engineering work is making a substantial contribution toward a company profit.

To evaluate the department's performance on this one category of work, something more is needed. For example, the rate of return contains no information to indicate whether development costs were at a proper level, nor does it indicate whether the most productive projects have been developed. There is, therefore, need for some standard or acceptable rate of return for various types of activities so that, for example, we could compare the rate of return on one project with another similar project or with other potential projects of greater return.

In establishing standard rates of return, recourse should be had to existing historical information and perhaps modified to recognize either general economic conditions at a particular time, or the company's peculiar financial position, or possibly to meet certain announced goals of the Industrial Engineering department. Specifically, at certain times, if there is a shortage of company

funds, the rate of return may be required to be very high, while in other more relaxed times, lower annual benefits of greater future duration and hence lower rates of return may be acceptable. Therefore, the standard rate of return may be adjusted accordingly.

SUMMARY

In summarizing the topic "How to measure and appraise your Industrial Engineering Department":

1. We would establish our departmental objectives for functions to be performed and basic results expected.
2. We would acknowledge that as yet we are able to calculate the dollar value of recognized company benefits on only a portion of Industrial Engineering work.
3. We would measure and appraise factors which experience has proven can enhance the probability of good performance.
4. On work with an expected measurable benefit, we would work with those parties concerned to arrive at an estimate of company benefits and for administrative purposes relate these in dollars to the cost of Industrial Engineering on that catgory of the department's work.
5. In our appraisal of departmental performance, we would consider as very important the reactions of top management and department managers served regarding work done for them.

In the final analysis, your company and mine need the best assurance they can get that the Industrial Engineering effort is earning a return on the cost of the department that is as great or greater than that which could be earned through other uses of company funds.

As indicated in this treatment of the subject, this need for assurance still exists and the means of providing this assurance still depends upon a combination of measurement and judgment, with a very large portion of the latter.

Reasons Used by Corporations to Justify Leasing of Trucks and Automobiles

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LEASING as a method of obtaining capital equipment and property is not new, but its use has become extensive only in relatively recent years. Most companies today are leasing some equipment, or have considered doing so. Industrial Engineers frequently are called upon to make economic studies of leasing versus purchasing. With such a widespread practice it might readily be assumed that decisions concerning leasing versus purchasing would be based, primarily, on economic factors, which method is cheaper. However, for some time there have been some indications that this might not be the case, and an investigation recently completed at the University of California revealed that in the majority of cases of automobile and truck leasing the decision probably is not based on costs. Further, it became apparent that in many cases corporations had not considered the relative costs of various possible methods of obtaining capital with which to acquire the desired equipment.

The leasing of motor vehicles has grown to important proportions during only the last ten years. It is estimated that in 1930 there were only 1,500 leased motor trucks in the United States. By 1954 the number had grown to about 60,000 and by 1956 to an estimated 225,000 (1). Reliable estimates are that the number of leased automobiles increased from about 80,000 in 1950 to over 350,000 in 1958 (2).

The phenomenal growth of automobile and truck leasing may not be repeated with other types of equipment. However, there is ample evidence that other types of assets are being leased more frequently than in previous years. It thus appeared desirable to learn the reasons used to justify automobile and truck leasing since these same reasons may also apply to other types of assets.

COMPANIES STUDIED

The companies studied numbered twenty-eight, all located in the San Francisco Bay area. All were corporations, but ranged in size from a nursery run by the proprietor and two employees leasing one truck to a large steel company having over 40,000 employees. A wide variety of industries was included in the sample, there being only two that might be said to be in the same business. The largest number of cars leased by any company in the group studied was 900. A number of the companies leased in excess of 100 automobiles. The median number was 55. Eight of the companies leased trucks; 50 trucks being the largest number leased by any of the companies. One of the companies had been leasing trucks for 24 years, and another company had been leasing automobiles for 12 years. Several were national organizations or branches of national organizations. Almost all of those leasing trucks had previously owned their equipment. It

may thus be said that the companies were representative and that their experience with leasing coincided very well with the period of major growth of automobile and truck leasing.

TYPES OF LEASING PLANS

Basically a lease is an agreement whereby an owner of property or equipment, called the lessor, conveys the item in question to another party, called the lessee, for his use either for a specific or indefinite period of time in return for a specific rent or compensation. Furthermore, the period of time of use by the lessee, if indefinite, must be limited, and it should be the intention of both parties that the proporety be returned to the lessor at the termination of the contract. Also, the total financial liability of the lessee must not be equal to the price or value of the goods or equipment leased. Unless the latter two restrictions are met the transaction may be classified as a conditional sales contract and the payments may not be deducted as an operating expense when computing income taxes.

Virtually all automobile and truck leases can be classified in one of three types. Under a *full-service lease* everything is provided by the lessor except a driver and gasoline, and in some cases even the gasoline may be provided. This type of lease obviously takes all responsibility and worry concerning maintenance away from the lessee. The lessor pays for collision, fire, and theft, and comprehensive insurance, while the lessee pays for public liability and property damage insurance. Thus the general conditions of this type of lease provide a fully serviced vehicle at a fixed cost to the lessee.

A *straight lease* differs from a full-service lease in that maintenance, insurance, and other services are not provided. The lessee obtains the vehicle for a fixed monthly charge for a specified number of months but it is his responsibility to see that all maintenance service is performed. In some cases the lessor will write a separate contract to provide maintenance and repair services in return for a specified charge *per mile* driven. The essential difference between such combined contracts and a full-service lease is that whereas the latter is based upon a fixed fee regardless of mileage driven, the combined contracts relate those costs of the lessor which are functions of mileage driven to a charge per mile.

The third type of lease is the *finance lease*. In this type of contract the lessee theoretically acquires an equity in the vehicle he is leasing. Normally the lessee agrees to pay a specified percentage of the cost of the vehicle each month plus an interest charge. When the lease is terminated the car or truck is sold to the highest bidder and if the total of the sale price and the lessee's theoretical equity is equal to the original cost of the vehicle the transaction is complete. If the total is greater than the original cost the lessee may share some of this profit. If the total is less than the original cost the lessee must absorb the loss.

Of the 26 companies for which the information could be determined, 18 used the full-service lease plan. Seven companies used the finance-lease plan, and only one used the straight lease. In general, it was found that those lessees who used large fleets—100 vehicles or over—tended to use the finance-type lease, although there were a number of exceptions. This can probably be taken as an indication that these large fleet operators are willing to undertake the maintenance and servicing of their vehicles, and that when a considerable number of vehicles is involved they have found it more economical to do so, or at least believe that it is. In some cases large fleet operators can contract for the maintenance of a fleet on more favorable terms than would be available to operators of small fleets.

REASONS USED TO JUSTIFY LEASING

The principal reasons used by the various companies to justify leasing—the primary objective of the study—were, in order of their frequency, the following:

1. Working capital is freed for other uses.
2. There is an income tax advantage in leasing.
3. Maintenance and administrative problems are reduced.
4. Leasing costs less than other methods.

A few other reasons were mentioned but the above four were the predominant ones given.

Even if one had anticipated these four reasons, the order of frequency would undoubtedly be rather startling to many people, particularly engineers. In the hard-headed world of business one might naturally assume that such a decision would be made on the basis of costs. This very obviously was not the case. Most of the individuals interviewed explained in detail how their companies could use the capital that otherwise would be tied up in a fleet of cars or trucks to increase their profits. Yet only a few companies even attempted to show an analysis of the relative cost of obtaining this capital through leasing versus obtaining it by more conventional methods. Several admitted that leasing cost more than owning but were content since the profits earned were greater than they thought the cost of leasing to be. However, one could not help but wonder how they could be sure of this when it was rather apparent that in most cases no real knowledge of the cost of obtaining capital through leasing was available.

As to the supposed income tax advantage, this was cited in almost one third of the cases, although not as the primary reason for leasing. That a considerable number of companies and persons still adhere to the myth that there is a substantial tax saving accompanying leasing is not surprising since such claims persist in current publications, despite the fact that it has been shown by engineering economists and tax lawyers that there is no long-term advantage.

There is no question that maintenance and administrative problems are reduced when fleets of vehicles are

leased. The extent of this advantage is, of course, difficult to quantify. As might be expected, companies having large fleets reported little or no advantage in this respect, while small lessees felt the advantage played a significant part in their decision to lease. Only two of the large lessees used the full-service type of lease.

One thus comes to the fourth-place reason—leasing was believed to cost less. Five of the twenty-eight companies reported that vehicle costs had been lowered through leasing. However, no actual cost figures were produced in answer to some cautious inquiries, and discretion did not permit pressing the issue. A few individuals said the costs of leasing and owning were about the same, but again no specific cost data were produced. But the majority said they recognized that leasing probably cost more.

Several of the miscellaneous, but apparently nondecisive reasons given for using leasing were interesting. Several felt that the fact that the costs accompanying leasing are known well in advance, and are regular, fixed, monthly charges, was an important advantage. Several companies which leased cars for salesmen felt that the plan assured new, better-appearing cars and that the better impression created was a significant advantage. Smaller companies felt that leasing got them out of an activity, fleet operation, which was foreign to their major activities and about which they were amateurs.

ANALYSIS OF LEASING AS A CAPITAL SOURCE

Since the freeing of capital through leasing was such a predominant reason given for using leasing, it is desirable to take a closer look at this concept. Basically leasing is simply one method of obtaining capital, and obtaining capital by this method involves a cost just the same as when it is obtained in one of the more conventional methods, either through borrowing or the sale of equities. Leasing is a method of borrowing capital. It has been compared to a 100 percent mortgage. One must therefore question whether the capital required for automobiles and trucks could be borrowed or otherwise obtained at a lower cost than through leasing. At least one might expect that business would make such a cost comparison. Yet this survey indicates that this was not done in the majority of cases.

Unfortunately there was no way of determining the rate of profit made by the various leasing companies involved in the study. But since more and more companies have entered this field in recent years, and those already in it have expanded their activities, it seems reasonable to conclude that they are making an attractive profit. While they usually enjoy some advantages over the lessees in respect to purchasing and resale of the vehicles involved, it is quite obvious that the rental paid by the lessees includes an adequate profit for the lessors. One is still left looking for the answer as to why companies prefer to obtain capital through leasing rather than by other methods, and are apparently not much concerned with the cost.

Several economic studies have indicated that the cost of capital has relatively little effect on expansion of business activities *provided* managers can feel reasonably sure of producing income which will exceed the costs, including any charges for capital, by a satisfactory margin. Certainly the results of this study bear out this concept. All of the companies studied indicated that they had good opportunities for using all the capital they could get. Leasing provides some of this capital, but one must still question whether any business can afford to use any source of capital without knowing its cost or without determining whether the same amount of capital could be obtained from another source at a lower cost.

The preference of companies for using leasing as a means of obtaining capital, rather than by other types of debt financing, seems to be influenced by custom. Debt financing varies widely from industry to industry. In some the practice is well established. In others debt financing seems to carry financial stigma. Obviously debt financing does, to some extent, cramp management flexibility. Companies naturally want to maintain a good credit position, but should this position be maintained without regard to cost?

Finally, it is even probable that in some cases equity financing might be more economical than obtaining capital through leasing. But without knowing the cost of capital through leasing it is obvious that a valid determination of the relative costs of the two methods cannot be made.

CONCLUSION

This study does not purport to indicate that leasing of vehicles is either cheaper or more costly than owning them. In some cases leasing is more economical; in others it is not. The study does indicate, however, that the majority of the companies studied based their decision to lease on the fact that it provided a source of capital, and either did not actually know or were rather unconcerned with what such capital cost. It also appears that in many cases companies might find it profitable to consider other sources of capital for financing motor vehicle fleets, and to make comparative cost studies of the different sources.

REFERENCES

(1) *The New Yorker*, XXXIV, No. 7, June 14, 1958, p. 25.
(2) "The Dealers Join In," *Business Week*, April 26, 1958, pp. 58-65.

President's Message

GEORGE H. GUSTAT
President, American Institute of Industrial Engineers, Inc.
1958-59

The Importance of Participation

IN TWO previous messages I have talked about human relations and professional relations as these two relate to the field of Industrial Engineering. Consideration of how the individual Industrial Engineer can either achieve or enhance his position, and that of his profession, is now in order.

It seems to me that the degree to which an individual Industrial Engineer can achieve his objectives, enhance his position and that of his profession is dependent primarily upon the manner and extent to which he actively participates in a number of activities. In this article I will outline three broad areas of activity wherein the Industrial Engineer can actively participate and thus achieve some of these objectives.

Broadly speaking, these three activity areas can be itemized as follows:

1. Participation in daily Industrial Engineering projects.
2. Participation in extending the application of known Industrial Engineering principles and techniques and the development of new principles and techniques.
3. Participation in professional, community and civic endeavors.

Let us discuss the first of these activities, namely, participation in the daily practice of Industrial Engineering. For many years the practice of Industrial Engineering has been considered to consist of work measurement incentive applications, and manual workplace methods. During the past twenty years, however, the sphere of activity of the Industrial Engineer has been enlarged to include process and operation analyses, man-machine relationships, plant layout, materials handling, production planning and control, quality control, statistical and mathematical applications, to name but a few. With this increase in scope of Industrial Engineering activity, the Industrial Engineer now has at his disposal the necessary tools and techniques required to predict and evaluate the design of a particular system.

We are all familiar with the tremendous technological developments that have taken place during the past fifteen years. We have seen many cases in which automatic equipment was unable to replace the operator—it merely altered his responsibilities. We have also seen cases where the expected return on capital investment, predicted for a proposed mechanization program, did not materialize. This resulted from a lack of thorough understanding of the proposed system—that is, omission or errors in predictions relative to the performance of the entire system. In the light of contemporary knowledge, it goes without saying that the total direct and indirect labor costs, waste, inventory requirements, scheduling requirements, material costs, maintenance costs, etc. are items that must be taken into full consideration in a systems analysis, and it is here that the Industrial Engineer can be of utmost value.

In some cases a simple workplace mock-up and the use of predetermined time values are the only tools required to predict the effect of a particular proposal. In

other cases a detailed man-machine relationship analysis is required. In still others a mathematical model or system simulation of the proposed system may be desirable. These are analyses that an Industrial Engineer should be competent to make. Each of these approaches requires an understanding of the systems concept which implies consideration of all phases of a problem.

In this general field of systems design the Industrial Engineer has a much larger role to play than he has ever had in the past. So far as participation is concerned, his long range success will largely depend upon the extent to which he himself displays initiative, origination, and active participation as a member of the analytical team.

By and large, the extent of advancement and application of modern Industrial Engineering techniques is not too generally known in industry. Said another way, Industrial Engineers in this day and age are better equipped through training and experience to handle more difficult and complex problems than generally confront them. This means, therefore, that we have a selling job to do in convincing people that we are able to tackle problems of greater scope and importance than we have been asked to solve in the past. This statement naturally assumes that we have gained professional respect from doing a satisfactory job on those assignments in which we have participated. Added respect and responsibility must always be earned. We cannot expect to be asked to participate on more complex projects if our past record on simpler projects has been only mediocre. There will also be occasions when the Industrial Engineer will not be invited to become a member of a project group. This usually results when those responsible for particular projects are not familiar with the scope and the capabilities of Industrial Engineering, and hence are not in a position to recognize the contributions that can be made by a competent Industrial Engineer. In these instances the Industrial Engineer must take the initiative to sell himself and his professional capabilities to those responsible individuals so that he can become a part of the project group.

The selling of himself and his services is not an easy task, but it certainly is a challenging and rewarding experience. As the Industrial Engineer actively participates in a greater number of projects and increasingly important projects, so also will he gain broader professional recognition in his day-to-day job.

The second broad area of participation in which I think it is important for an Industrial Engineer to be involved is that of extending the application of known Industrial Engineering principles and techniques, and the development of new principles and techniques. It is assumed that before he can accomplish these objectives he must have become familiar with all present day Industrial Engineering techniques. In addition, he must actively seek opportunities to try out those techniques with which he is not familiar. This usually requires some experimentation. There are many present day techniques available which are not being used by the practicing Industrial Engineer in his daily work. He must experiment with these techniques, record the results of his experiment, analyze the effects and preferably publish his conclusions. Only by such feed-back of experimental results can we continually refine our techniques, extend their applications, and make this knowledge beneficial to the greatest number of Industrial Engineers.

I believe that a substantial amount of experimentation has been and continues to be pursued in our profession. However, only a fraction of this information is submitted for publication in *The Journal of Industrial Engineering* or elsewhere. Each Industrial Engineer can enrich his experience by participation in the areas of development and extension of Industrial Engineering techniques. As we develop and extend Industrial Engineering techniques, so also will we acquire further capabilities which in turn will earn us the opportunity to analyze more difficult and complex problems.

The third broad area of participation which I wish to discuss is the role of the Industrial Engineer in professional, community, and civic endeavors. The remarks that I make concerning this subject might well apply to all engineers. The engineering profession is an extremely sizeable one in numbers of people. However, the voice of the profession is not at all in proportion to its size. We might well ask ourselves why this is so, and the answer I think is quite obvious. Generally speaking, engineers have not participated in professional, community, and civic activities to the extent of other professions. It is safe to generalize that the engineering field is oriented toward problem solving. In this respect we might ask ourselves, with all the problems that face the world why then are not engineers more deeply involved in the solution of these problems. Again, the only conclusion that can be drawn is that engineers have apparently lacked interest and thus have failed to actively participate in projects outside the scope of their professional practice.

Broadly speaking, Industrial Engineering's main theme is the quantitative evaluation of alternative courses of action in a decision making situation. It seems to me that there are many important decisions facing society which might be more intelligently made if such an approach were taken.

Mr. James R. Killian, Jr., a renowned engineer statesman, recently stated,

> Our nation now asks of its engineers that they be more than technicians and narrow specialists, that they henceforth have a deeper grasp of the scientific principles and concepts fundamental to their understanding of nature and a broader foundation of liberal education embracing an understanding of man. It asks for more engineers who can, while achieving exceptional mastery of their specialty, avoid the easy, narrow rut of "excessive expertism" and go on to demonstrate as engineers leadership in human affairs —the capacity to use and shape technology as a powerful instrument for enhancing the quality of our society and for contributing to the great human problems of our time.

Engineers do have a contribution to make to society and to the great human problems of our time. In addition, engineers can also gain from taking part in outside activities. Such factors as broadened perspective, experience in working with people, the opportunity to develop and exercise leadership abilities, the opportunity to organize, plan and direct projects toward worthwhile objectives, practice in public speaking, the gaining of self-confidence and added maturity are just a few of the gains that can result to the individual engineer who actively participates in professional, community, and civic activities.

In conclusion, I should like to state that respect for and recognition of engineering as a profession can only be earned as the direct result of our having made effective contributions to society. Engineers must stir their stumps, take the initiative and become actively engaged in outside activities if they expect to gain the same stature in society that is held by other professions. The American Institute of Industrial Engineers offers the best medium to achieve this.

Active participation in the three broad areas that I have outlined in this article is the challenge that faces each one of us. Only by concerted effort in these areas can we hope to continually improve ourselves, our profession, and our society.

Recent Readables

COST REDUCTION AND CONTROL

"How to Make Today's Production Controls Cut Costs in Your Plant," An Interview, FACTORY MANAGEMENT AND MAINTENANCE, *page 63, June, 1958.*

A top man in Production Control at General Electric, Mr. H. F. Dickie, discussed with a Factory Editor what's new and what's ahead in Production and Inventory Management, updates tried and tested methods, and tells how today's best techniques can be adapted in any plant—large, medium or small.

"Designing To Reduce Down Time," by D. I. Dumond, MECHANICAL ENGINEERING, *page 61, December, 1958.*

Maintenance costs can be controlled through design. Although the designer may incorporate many components and parts in his design which may never require maintenance, there are others that must be maintained. If he has not reviewed his design to be sure that he fulfills three important criteria, it may require excessive maintenance. This paper outlines these three criteria which were found to be effective in controlling maintenance costs by reducing down time.

GENERAL

"Better Make or Buy Decisions," by E. B. Cochran, FACTORY MANAGEMENT AND MAINTENANCE, *page 40, December, 1958.*

Good make-buy analysis can spot non-competitive shop practices, reveal the inefficient vendor, pinpoint needed changes in Plant and Equipment.

The author describes his plan for supplying top management with all the facts, properly analyzed, which will lead to valid conclusions and profitable decisions. Four typical problems illustrating major questions that need answers are presented.

"What You Will Pay For What You Want in Your New Plant," Survey by Editors, FACTORY MANAGEMENT AND MAINTENANCE, *page 52, December, 1958.*

This is a report on the cost of eight nearly new manufacturing plants.

Plant construction-cost yardsticks can not be generalized. There are too many variables to consider. For instance, in any one of these eight buildings aside from size there are at least 10 factors affecting cost that differ.

The 10 variables are: 1. processes, 2. products, 3. geographical location, 4. plant site features, 5. design in terms of function and efficiency, 6. design in terms of architecture, 7. type and quality of construction, 8. labor and materials, 9. market conditions generally, and 10. the time of bidding and the value of the dollar during construction.

"Maintenance Management Practices in Industry Today," by C. W. Boyce and C. G. Wyder, FACTORY MANAGEMENT AND MAINTENANCE, *page 90, September, 1958.*

An 18 page report of Factory's Survey on Current Maintenance Practices and on Trend's *Shaping* The Future. The conclusions based on the 359 Plants reporting in the Survey are listed under eight headings as follows:

1. "Size of the maintenance force."
2. "Clerical help."
3. "Place of maintenance in the plant organization."
4. "Maintenance cost records."
5. "New analysis techniques."
6. "Maintenance staff and supervisory personnel."
7. "Updated facilities."
8. "The finest maintenance job."

"Managerial Decision Making," by H. F. Smiddy, ADVANCED MANAGEMENT, *page 5, October, 1958.*

"Managerial decision-making" would be vastly improved if most managers—very particularly, most higher-level managers—would make far fewer decisions; but have, in turn, far more time and far better atmosphere for unhurried contemplation and consequently more deeply decisive treatment of matters rightly and legitimately reserved for their consideration and determination.

The author states that most executives, today, have more information than they have either time or analytical capacity to use in any such detail; and that, as a result, they try to make too many decisions that others in the organization could make bette-,

and ought to be required to make instead of putting what should be their job upstairs in the boss' office!

"Factory's Guide to Managed Modernization," by the Editor, FACTORY MANAGEMENT AND MAINTENANCE, *page 80, November, 1958.*

This 58 page report summarized by the Editors is as follows:

1. What "Managed Modernization" means.
2. It's a concept, not a procedure.
3. It's systematic, not hit-or-miss.
4. It's balanced.
5. It's geared to customer demands.
6. It's easy to get started.
7. It's hardboiled but fair.
8. It's practical.

LAYOUT

"The Allocation and Layout of Office Space," by A. W. Clark, THE OFFICE, *page 69, December, 1958.*

A complete procedure for planning your present and future office space requirements. Step by step, the author describes how and why specific space is allotted to each department. The formulas he uses are applicable to most offices.

MARTERIALS HANDLING

"The ABC's of Yard Storage," by Editors, MODERN MATERIALS HANDLING, *page 72, December, 1958.*

Skyrocketing building costs are adding urgency to the need for new, low-cost storage methods. The "Warehouse without a roof" has met this need in many plants. Here's a review of some fundamental factors in yard storage analysis and planning.

"Should You Use Mechanized Storage?", by E. E. Moon, MODERN MATERIALS HANDLING, *page 67, December, 1958.*

Sales policy and production methods are but two of many external factors that affect the economics of warehousing operation. If costs are getting out of hand, consider mechanized storage.

It is true that many of the reasons for high warehousing costs do not stem from lack of efficiency in handling. Rising labor costs, limitless package variations and selling policies must also bear some of the blame. However, new and improved controls and conveyor equipment make possible substantial increases in efficiency, particularly in order filling. Having made all possible gains from the basic principles of good organization, the warehouseman is ready for mechanization. The equipment is available, but its effective application demands careful study on the part of potential users.

"Selection and Use of Belt Conveyors," by B. E. Kennel, MATERIALS HANDLING ENGINEERING, *page 64, December, 1958.*

The first in a series of articles designed to give materials handling engineers important technical information on all types of conveyors. It covers both flat and troughed belt conveyors. Following articles will report on elevators and boosters; portable and telescopic conveyors; en masse and flight conveyors; trolley and tray conveyors; roller and wheel conveyors; screw and spiral conveyors; reciprocating, vibrating, and oscillating conveyors; pneumatic and pneumatic tube conveyors; chain drag, and push bar conveyors; floor and slat conveyors; apron and bucket conveyors.

"Walkies—What They Can Do and Can't Do," by P. Schreck, MODERN MATERIALS HANDLING, *page 78, December, 1958.*

The so called "Walkie" industrial truck, a type of powered truck which is guided by a walking operator, has contributed to a major advance in mechanized handling. As a supplement to conveyors or systems employing larger rider type industrial trucks, they have now come into their own as a basic handling tool.

This article presents advantages and disadvantages of the "Walkies."

ORGANIZATION

"Role of a Management Engineering Staff at the Corporate Level," by H. H. Fite, ADVANCED MANAGEMENT, *page 14, October, 1958.*

The prevalence of decentralized operations in today's business economy brings with it the major problem of exercising centralized corporate control. Hence, many businessmen seem currently to have a lively interest in the so called "intra-company management engineering staffs." These are staffs within a company or corporation which render more or less the same kind of service rendered by the consulting management engineering profession. While a number of articles have been written on this subject in times past, they have concentrated on how such staffs function and tended to deal only a glancing blow to the question of where such groups properly fit into the corporate scheme of things. This article is written on the topic of organizational placement and interrelationships of such staffs at the corporate level of an enterprise.

WORK MEASUREMENT

"Semtar—Newest Motion Timer and Recorder," from W. J. King's Casebook, FACTORY MANAGEMENT AND MAINTENANCE, *page 162, September, 1958.*

Semtar stands for Sequential Electronic Motion Timer and Recorder. It's an automatic electronic timer and recorder developed by the Industrial Engineering Division at University of Minnesota's Institute of Technology. Initial application will be in basic research on hand motions used in industrial and clerical work and checking established predetermined time systems. With minor modifications, it could be used for psychological, engineering, and medical research.

WORK SAMPLING

"8 Tips to Help You Save Time," by C. L. Brisley, FACTORY MANAGEMENT AND MAINTENANCE, *page 60, December, 1958.*

The author presents the results of a Work Sampling Study on Operating Managers taken over a 15 week period. Results indicate a typical manager spent about 82% of his time in talking, 4% in writing, 11% in reading, 1% in clerical and only 2% in thinking. The author presents 8 tips suggested by the managers for making their communications work easier.

"What Makes Work Simplification Work," An Interview, FACTORY MANAGEMENT AND MAINTENANCE, *page 72, July, 1958.*

An interview by Factory Editors L. R. Bittes and C. W. Boyce with pioneers, Lillian Gilbreth, A. H. Mogensen, E. H. Schell, David B. Porter and H. F. Goodwin.

"Gives Over-all Work-Effort Picture," by W. J. King, FACTORY MANAGEMENT AND MAINTENANCE, *page 109, December, 1958.*

An aircraft company graphically follows the performance of production departments through weekly ratings posted to large wall charts. The information comes from a new system called PACE (Performance and Cost Evaluation). It measures group performance in a non-repetitive shop by applying a sampling approach to efficiency rating.

The PACE Measurement Index is plotted on a chart in weekly increments. It is the basic index for indicating the trend of group

effectiveness. The goal for each organization is to bring the PACE line up into a "control area" of the chart. This control area ranges from 85 to 100% of optimum normal effectiveness. Investigations indicate 55 to 65% is common in the airframe industry. Similar logs in efficiency may be found in other industries where individual production rate controls are difficult to apply.

"Make Work Simplification Work For You," by H. F. Goodwin, FACTORY MANAGEMENT AND MAINTENANCE, *page 76, July, 1958.*

As stated by the author "Work Simplification as a management philosophy may be defined as the organized use of common sense to find and apply better ways of doing anything. Improvements are of little value unless they are effectively used. It is common sense to utilize all of the brains available. It is logical to budget the proper amount of participation in keeping with the importance of the activity. We thus arrive at better improvements and at the same time develop the atmosphere for effective application. It is far better to invest time in creating acceptance to change than in attempting to overcome resistance to it."

BOOKS

OFFICE MANAGEMENT HANDBOOK, *by Harry L. Wylie, Ronald Press Co., New York 10, $12.*

Developed under auspices of the National Office Management Assn., this second edition provides a practical guide to efficient office organization and the optimum use of systems, personnel and equipment. While pointing out the advantages of electronics automation and allied developments, it emphasizes standard performance factors, standard materials and standard costs for use as yardsticks in any organization. Foundation of the book's 21 sections is the successful experience of well-run companies as reflected throughout the literature of business and the findings of office management authorities. Illustrations include more than 250 charts, tables, forms and drawings. Mr. Wylie, assistant secretary-treasurer of Pure Oil Co., was assisted by James Q. Harty and 32 contributing editors.

THE MATERIALS HANDLING HANDBOOK, *edited by Harold A. Bolz and George E. Hagemann, Ronald Press, New York, 1,750 pages, $20.*

This latest volume on materials handling is said to be one of the most complete reference works available on the subject.

Illustrated with photographs, charts, tables and diagrams, the work is divided into 47 sections covering methods of analyzing handling problems, principles, procedures and techniques for effective operation and control; systems design and installation; integration of materials handling activities with the manufacturing processes; plus the design, selection and classification of materials handling equipment.

MANUFACTURING POLICY, *A Casebook of Major Production Problems in Six Selected Industries, by Stanley S. Miller, Richard D. Irwin, Inc., Homewood, Ill., 1958, 807 pages, $14.40.*

This casebook of production problems in the furniture, cotton textiles, plastics, television set assembly, steel manufacturing and oil industries focuses attention on decisions at the vice-presidential level. Designed for graduate students, it endeavors to provide a clear insight into the actual problems and responsibilities of top management through the study of related cases within a single industry. The competitive conditions and manufacturing processes of each of the six industries are described in detail, and comprehensive data are provided on the actual operating costs, growth trends, competitive moves, and plant processes of the individual companies studied.

THE RESULTS APPROACH TO ORGANIZATION, *by Edward C. Schleh, Society for Advancement of Management, 74 Fifth Ave., New York 11, 21 pages, $1.50.*

Most management is weak and costly because executives don't know the specific results expected in their job; emphasis is on activity rather than results. The executive's accountability for performance therefore is diluted or does not exist. Executives and their subordinates lack the initiative and motivation for maximum contribution to the buisness. The "results" approach sets a measurable yardstick for line and staff, creates balanced effort throughout the organization, releases individual creativity and initiative by making each job a replica of the job above it.

MANAGEMENT IN A RAPIDLY CHANGING ECONOMY, *edited by Dan H. Fenn, Jr., McGraw-Hill, 330 West 42nd Street, New York 36, 360 pages, $5.00.*

Forty-one top level executives consider in what rapidly changing environment will the nations businesses have to be managed in the next decade. A compilation of speeches and discussions at the Harvard Business School's 27th National Business Conference, the book provides an assessment of the many technological, social, marketing and economic changes already underway and the risks and potentials inherent in them.

PROCEEDINGS OF THE FIRST NORTHEASTERN REGIONAL CONFERENCE OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, *held October 29 and 30, 1958, in Syracuse, New York, paper-bound, 172 pages, price: $5.00.*

There were sixteen conference speakers. Orders should be directed and checks made payable to Manufacturers Association of Syracuse, 351 South Warren Street, Syracuse 2, New York.

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TENTH ANNUAL AIIE CONFERENCE AND CONVENTION PROGRAM

May 14, 15 and 16, 1959

Biltmore Hotel, Atlanta, Georgia

THURSDAY, May 14, 1959

8:00 A.M. Registration

9:00 A.M. Keynote Address:

The Sociological and Technological Evaluation of Industrial Engineering; The Present Status; A Projection of the Future

George H. Gustat

National President AIIE, Director of Industrial Engineering, Eastman Kodak Company

10:45-12:00 A.M.

A-1 Feasibility Analysis in Product Diversification

Ernst W. Swanson

Senior Research Economist, Industrial Development Branch, Engineering Experiment Station, Georgia Institute of Technology

B-1 Industrial Application of Memo-Motion

Samuel W. Earle

Manager of Industrial Engineering, Union Carbide Corporation

C-1 Need for Industrial Engineering Technique in Product Development

Benjamin W. Niebel

Head of Department of Industrial Engineering, Pennsylvania State University

12:30-2:00 P.M. Luncheon

Productivity—Key to American Standard of Living

A. C. Kotchian

Vice-President of Lockheed Aircraft Corporation and General Manager of Georgia Division; President of Associate Industries of Georgia

2:30-3:45 P.M.

A-2 Organization for Better Utilization of Industrial Engineers

Raymond Villers

Partner, Rautenstrauch and Villers

B-2 Is There Something Better Than Monetary Incentives for Maximum Productivity?

Stephen L. Palmert

Chief Industrial Engineer, Harley-Davidson Motor Company

C-2 Producibility Analysis—A Challenge to Industrial Engineers

Frank J. Johnson

Manager, Production Engineering Design Analysis, Lockheed Aircraft Corporation

4:15-5:30 P.M.

A-3 Communication Theory and Practical Applications

Allen B. Rosenstein

Professor, University of California

B-3 A New Approach to Work Simplification Techniques

Floyd Simerson

Director of Work Simplification, Sears, Roebuck and Company

C-3 Basic Fundamentals of Computers

M. A. Schader

Manager, Engineering and Sciences, International Business Machines Corporation

7:00 P.M. Annual Banquet

Humanics of Industrial Engineering

Jerome Barnum

Jerome Barnum Associates

FRIDAY, May 15, 1959

9:00-10:15 A.M.

A-4 Establishing Incentives through Collective Bargaining

William Gomberg

Visiting Professor, Columbia University

B-4 Science and Industrial Complexity—The Industrial Engineer's Challenge

M. E. Salveson

President, Center for Advanced Management

C-4 Data Processing and Inventory Control Problems

R. A. Harrison

Branch Manager, International Business Machine Corporation

10:45-12:00 A.M.

A-5 Management in the Electronic Age

Frank Middleswart

Coordinator of Engineering Services, E. I. du Pont de Nemours

B-5 Specific Techniques of Operations Research

Robert D. Ferguson

Methods Engineering Council

C-5 Techniques of Computer Feasibility Studies

Grace Murray Hopper

Director of Programming Research, Remington Rand-Univac

12:30-2:00 P.M. Luncheon

Engineers Are People

Noah Langdale

President, Georgia State College

2:30-3:45 P.M.

A-6 Modern Materials Handling—The Four Legged Concept

John W. Lay, Jr.

Chief Engineer, IMC Equipment, Inc.

B-6 Work Sampling Applied to Simulation Systems

Chester L. Brisley

Staff Assistant to Director of Production, Chance-Vought, Inc.

C-6 Automation—A Case Study

H. R. Bentley

Plant Manager, Engine Division, Chrysler Trenton Plant

4:15-5:30 P.M.

A-7 Advanced Materials Handling Techniques in Product Distribution

James M. Apple

Professor, Department of Industrial Engineering, Michigan State College

B-7 Principles of Management Control Systems

E. H. Mac Niece

Technical Consultant, Permacel Corporation

C-7 Automation and Materials Handling—A Problem in System Coordination

E. H. Abbe

Equipment Engineering Industry Control Department, General Electric Company

ADVANCED RESEARCH SESSIONS

Thursday, May 14, 1959

10:45-12:00 A.M.

The Effect of Deferable Work on Waiting Line Problems

Robert W. Peacor

Industrial Engineering Division, Eastman Kodak Company

2:30-3:45 P.M.

A Job Design Research Program

Louis E. Davis

Professor, University of California

4:15-5:30 P.M.

Simulation Research on Shop Scheduling

Richard W. Conway

Department of Industrial and Engineering Administration, Cornell University

Friday, May 15, 1959

9:00-10:15 A.M.

Use of Log-Normal Distribution for Relating Inventory Levels and Customer Service

R. G. Brown

Arthur D. Little and Company

2:30-5:00 P.M.

Contributed Research Papers

CHIEF INDUSTRIAL ENGINEERS' SYMPOSIUM

Thursday, May 14, 1959

10:45-12:00 A.M. Panel Session No. 1

Industries Need Versus Education Supply

Frank F. Groseclose

Director, School of Industrial Engineering, Georgia Institute of Technology

Clifton A. Anderson

Head, Department of Industrial Engineering, North Carolina State College

Robert J. Rohr

Assistant Director of Industrial Engineering Division, Eastman Kodak Company

Richard F. Bergman

Vice-President of Engineering, Link Belt Company

2:30-5:00 P.M. Panel Session No. 2

Present Scope of the Industrial Engineering Department

Grover N. Meinert

Chief Industrial Engineer, Atlantic Steel Company

Mark L. Wilton

Chief Industrial Engineer, Lockheed Aircraft Corporation

John M. Murray

Chief Industrial Engineer, Vanity Fair Mills

Omar K. Vanament

Chief Industrial Engineer, Conway Division of Virco Manufacturing Company

Friday, May 15, 1959

2:30-5:00 P.M. Panel Session No. 3

The Role of Electronic Equipment in the Industrial Engineering Department

Harold D. Deaton

Branch Manager, Remington Rand Division, Sperry-Rand Corporation

H. E. Harris

Branch Manager, International Business Machines Corporation

Cleggett A. Jones

District Manager, Electro-Data Division, Burroughs Corporation

John S. Nesbitt

National Marketing Manager, Government and Industrial Division, Philco Corporation

SATURDAY, May 16, 1959

8:00-9:00 Delegation Registration

9:00-12:30 Convention

12:30 Luncheon

1:30 Acceptance Address by President Elect

SCHEDULE OF FEES

	Member	*Non-Member*
Full Conference	$39.50	$49.50
This includes all sessions on Thursday & Friday, two luncheons, one banquet and proceedings. The convention luncheon on Saturday is *not* included.		
Thursday Only	$24.50	$29.50
(All Thursday sessions and one luncheon includes proceedings)		
Thursday Luncheon Only	$ 7.00	$ 7.00
Friday Only	$24.50	$29.50
(All Friday sessions and one luncheon includes proceedings)		
Friday Luncheon Only	$ 7.00	$ 7.00
Saturday Convention Luncheon	$ 5.50	$ 5.50
Saturday Convention	free	
Banquet Only (on Thursday)	$12.50	$12.50
Proceedings Only	$ 5.00	$ 7.00
Undergraduate Students, High School Teachers & Vocational Guidance Counsellors	$ 2.00	$ 2.00
(All Thursday and Friday sessions. Luncheons and banquet are not included)		
Ladies Program	$20.00	$20.00
For the wives and full registrants. This includes the Thursday banquet and a full program of activities during the two days of the Conference.		
"Y'all Come" Party (on Friday night)	$ 8.50	$ 8.50
To be held at famous Aunt Fanny's Cabin (Southern Fried Chicken and Barbecue)		

NOTES:

1. Luncheon and banquet seatings can be guaranteed only if advanced registrations are made.
2. The Conference, Thursday and Friday, is open to non-members as well as members. The Convention meeting and luncheon on Saturday are open to members only.
3. For a detailed announcement or registration write to: AIIE, P.O. Box 5255, Station E, Atlanta 7, Georgia. Checks are to be made payable to: "Tenth National AIIE Conference."
4. Refunds for cancelled reservations will be made only if notice is received prior to May 12, 1959.

PROFESSIONAL RELATIONS ACTIVITIES

Engineering Unity

Interest in unity within the engineering profession dates back to 1852 when the first engineering organization—The American Society of Civil Engineers—was founded. Since that time the number of engineers (or persons calling themselves engineers) has grown to a Census Bureau estimate of about 700,000. Over the same period of time more than 100 different organizations of engineers have been formed. Engineers have banded together primarily because of their interest in a particular technical field and this probably accounts for most of this "splintering."

However, this growth and subsequent splintering has contributed to a unique situation: The importance of the engineer in our modern society can not be denied nor can the extent to which he participates in matters dealing with our national well being. Yet there is no organization that can speak with one voice or act as one body in developing the professional interests of individual engineers; nor has there been formed a single organizational contact for the benefit of government agencies, other professional organizations, and the general public.

Furthermore, the duplication of interests, the unavoidable overlapping of functions, must account for a staggering waste of professional and executive time on the part of officers and committeemen. At the National level the end result must be a dilution of activity and at least a diffusion of energy that could perhaps have been better concentrated on common objectives.

Some engineers see unity as a step backwards—others see in unity our only hope for attaining professional recognition comparable to the status enjoyed by the Bar and Medical professions. Discussions have waxed quite warmly on this subject. Meanwhile the total number of engineers continues to grow as students graduate from engineering schools and, if history is any teacher, there is little hope for a decrease in the total number of engineering organizations. In the face of this trend, professional unity can hardly continue to be a matter of contention—rather it must be viewed as a matter of time for it appears to be inevitable in one form or another. If the engineering mind—speaking collectively—is capable of solving the complex technical problems facing us today then surely it is capable of conceiving a coordinated pattern of activity that will reduce or eliminate the duplication of effort and wasted energy in this area of professional development. The factors to be reconciled are many and quite realistic:

1. Some of the societies believe they are adequately and sufficiently protecting and enhancing the professional welfare of their own members.
2. The scope of activities in which professional societies may engage, is affected by their tax status to some extent. Contrary to widespread belief, there are different categories of tax classifications which free the organization involved from the obligation to pay income tax. Those within this group who are classified as educational or charitable or scientific associations are governed quite rigidly in the scope of their work by regulations of the Internal Revenue Code.
3. Some groups seriously believe that the variety of trained experts calling themselves engineers have really little or nothing in common; the range of requirements for full membership in societies in general is so wide as to make complete reconciliation difficult. For example, at one end is the National Society of Professional Engineers which stipulates registration as a requirement for membership; at the other end of the scale, there are societies who recognize and admit "friends of engineers" to full or separate membership.
4. Three organizations currently carry on part or all of the activities related to professional development:
   a. The Engineers Joint Council is a federation of professional societies whose membership exceeds a quarter of a million of engineers. It is dedicated to the betterment of the nation and to the professional and sociological development of the individual engineers. EJC functions through committees that study national manpower policy, engineers' employment conditions in industry, science and engineering education, secondary and technical school education, national resources policies, and modern technological developments such as nuclear energy and automation.
   b. The Engineers Council for Professional Development is a conference of engineering societies similar—though narrower—in structure to EJC. ECPD includes the five Founder Societies as well as the National Council of State Boards of Engineering Examiners. It has developed a nation-wide high school guidance program; it is carrying on the important job of accrediting engineering undergraduate curricula; it has undertaken a large scale experiment in post-baccalaureate training; it has developed a canon of ethics; it has participated with nations of Western Europe in conferences on engineering education and training.
   c. The National Society of Professional Engineers (which has approximately 45,000 members) devotes its entire effort to the professional, ethical, and social aspects of engineering. This society concentrates on the advancement of the engineering profession in the fields of employment practices, ethical practices, legislation, salaries and fees, military affairs, public relations, and the education of young engineers.

Quite a number of proposals for unification of the profession have been brought forth over the years. Some visualize a unity organization, others a unity program. Among all of these, two have received particular attention in recent years:

1. The "Functional Plan" first suggested by Dr. M. S. Coover (1956-57 President of American Institute Institute of Electrical Engineers) which in brief tends to support—with major modifications—the continuance of three organizations patterned after EJC, ECPD, and NSPE. Dr. Coover suggests basically that:
   a. Technical societies should provide the medium for the advancements in technology in their specific field of interest and activity.
   b. EJC provide the medium for coordination and cooperation on inter-society matters and also present to the public the position of the engineering profession on technological matters.
   c. ECPD provide the medium for guidance in engineering

education and should be delegated to represent the engineering profession in all educational matters.

d. NSPE provide the medium for the general promotion of the professional aspects of engineering in the eyes of the public. This would include advancing the economic status of the engineers.

e. NSPE must somehow expand its membership if it intends to speak for all engineers.

2. The second proposal was made by a committee from the American Society of Mechanical Engineers appointed by J. N. Landis, then President of ASME, on March 5, 1958. This group was instructed to study all the desirable features and advantages of the "Functional Plan" and submit recommendations for an organization that could deal effectively with the problems common to the entire profession. In short, this committee has recommended a modification of the "Functional Plan" in order to provide some means of administering and controlling the interdependent actions of the three functional organizations. Basically this committee recommends that:

a. EJC and ECPD take the initiative in establishing a unity organization.

b. NSPE be encouraged to participate in the activities of this unity organization in order to benefit by the extensive experience of the NSPE in the area of professional activity.

c. The responsibilities of EJC and ECPD be re-aligned into three major divisions, each under the direction of an executive committee:

1—Joint Educational Activities Division
2—Joint Technical Activities Division
3—Joint Professional Activities Division

d. The individual engineer be represented through membership in his own technical society.

e. A General Executive Committee be formed to administer and control the three divisions.

f. A Board of Directors be elected by societies with representation on the Board in proportion to membership.

g. Liaison be established between the United Engineering Trustees and the proposed Unity Organization.

This review has been made to acquaint the Industrial Engineer with recent activities in the field of professional development that will affect all of us as individuals.

The AIIE has a task force studying the problem of unity. Their report is awaited with interest by the Institute and the other engineering Societies.

Reported for the Professional Relations Committee
By O. J. Feorene

CALENDAR

April 13-14: Industrial Engineering Conference, Purdue University, Lafayette, Indiana. Theme: Cost Reduction: The Ever Present Challenge. Write: Dean James B. Ball, Office of the Dean of Engineering, Purdue University, Lafayette, Indiana.

April 17: Eighth Annual Spring Conference sponsored by the Cleveland Chapter of AIIE; the Cleveland Engineering and Scientific Center, 3100 Chester Avenue, Cleveland, Ohio. Theme: Preparing to Measure Tomorrow. Write: H. E. Norton, Axle Division, Eaton Manufacturing Company, 739 E. 140th Street, Cleveland, Ohio.

April 18-22: American Society of Tool Engineers Annual Meeting; Schroeder Hotel, Milwaukee, Wisconsin. Write American Society of Tool Engineers, 10700 Puritan Ave., Detroit 38, Michigan, Attention Harry E. Conrad, Executive Secretary.

April 23-24: Fourteenth Annual S.A.M.-A.S.M.E. Management Engineering Conference; Hotel Statler, New York City. Theme: Profitable Management Engineering—1959. Write: Society for Advancement of Management, 74 Fifth Avenue, New York 11, New York.

May 14-16: Tenth Annual National Conference and Convention, American Institute of Industrial Engineers; Biltmore Hotel, Atlanta, Georgia. P.O. Box 5255, Station E, Atlanta 7, Georgia.

May 14-15: Seventh Annual (and Fifteenth National) Meeting of the Operations Research Society of America; Shoreham Hotel, Washington, D.C.

May 14-23: International Petroleum Exposition. The Tulsa Chapter of AIIE has joined with sixteen other societies to sponsor the IPE Technical Societies' Registration Center for all engineers and technical men. The Center is to be in The Petroleum Engineer Publishing Company exhibit located at Texas and Mid-Continent Drive near the exposition grounds' main entrance.

May 17-22: Twentieth Paperwork Simplification Conference; The Edgewater Hotel, Madison, Wisconsin. Attendance limited to 20. Registration fee of $350 includes notebook, materials, meals and single room with bath. Write: Ben S. Graham, Paperwork Simplification Conferences, Tipp City, Ohio.

May 31-June 13: Second Annual Packaging Training Course; Industrial Management Center, Lake Placid Club, Essex County, New York. Write James R. Bright, Director, Industrial Management Center, 56B Robbins Road, Lexington, Massachusetts.

June 8-19: Intensive Course in Operations Research and Systems Engineering; Homewood Campus of The Johns Hopkins University, Baltimore, Maryland. Write: Dean, School of Engineering, The Johns Hopkins University, Baltimore 18, Maryland.

June 8-July 17: Southern Regional Graduate Summer Session in Statistics; North Carolina State College, Raleigh, N.C. Write F. E. McVay, Department of Experimental Statistics, North Carolina State College, Raleigh, N.C.

June 9-12: The Material Handling Institute's Exposition of 1959; Cleveland Public Auditorium. Write Hanson & Shea, Inc., Suite 759, One Gateway Center, Pittsburgh 22, Pennsylvania.

June 13-14: Planning and Controlling Capital Expenditures Conference featuring industrial applications of engineering economy and related management techniques; being held at Carnegie Institute of Technology and the University of Pittsburgh. This conference is sponsored by the Engineering Economy Division of ASEE and the Engineering Economy Research Committee of AIIE. The theme is "Applications of Economic Evaluation in Industry." Registration fee is $25.00 with a special rate of $5.00 for academic personnel. Write: Markwick K. Smith, American Telephone and Telegraph Company, Room 1104, 195 Broadway, New York 7, New York.

June 14-27: Sixth Annual Material Handling Training Course; Industrial Management Center, Lake Placid Club, Essex County, New York. Write James R. Bright, Director, Industrial Management Center, 56B Robbins Road, Lexington, Massachusetts.

June 22-July 3: Special Summer Session at Massachusetts Institute of Technology in Applications of Probability Theory to Operations Research. Tuition, $275. Write: Professor James M. Austin, Director of the Summer Session, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

August 17-28: Special Summer Session at Massachusetts Institute of Technology in Industrial Dynamics. Tuition, $325. Write: Professor James M. Austin, Director of the Summer Session, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

AKRON CHAPTER

The November meeting of the Akron Chapter was addressed by Mr. Fred H. Simon, International Representative of the United Auto Workers, who spoke on "The Union Viewpoint on Incentives, Time Study and Job Evaluation Systems."

Mr. John E. Schlacter, Manager of Employee Insurance and Pension Programs for the B. F. Goodrich Company, discussed

"The Economic Impact of the Fringe Package" before the December meeting.

Mr. Robert A. Wofsey, of Arthur Young & Company, spoke on "Cost Control Through Budgetary Control" at the January meeting.

Mr. John S. Petro, Thompson Products Company, will speak on "Ratio Delay Studies" or "Work Sampling" at the March meeting.

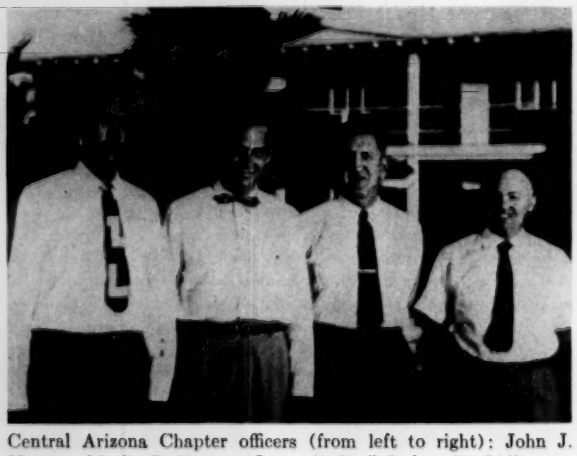
In April, Mr. J. F. Lincoln, Lincoln Electric Company, will speak on "Incentive Management."

The May meeting will be Ladies' Night. Miss Beth Peterson, E. I. duPont de Nemours and Company, will speak on "The New Look in American Living."

The June meeting will consist of a panel discussion and election of officers.

The Akron Council of Engineering and Scientific Societies (ACESS), which is composed of two members from each of the professional engineering and scientific societies in the Akron area, has developed a program to introduce Junior High School students to the engineering and scientific fields. The first phase of this program consists of assemblies for 8th grade students conducted by an ACESS speaker and includes a twenty minute film. R. A. Holmes, S. J. Miheliek, G. W. Timms and V. L. Smeltzer of the Akron Chapter AIIE are actively participating in this program as speakers.

CENTRAL ARIZONA CHAPTER



Central Arizona Chapter officers (from left to right): John J. Noonan, Merlin D. Vincent, James D. Huff, Robert W. Lidington.

The August meeting of the Central Arizona Chapter was addressed by Mr. H. E. Miller, the General Plant Manager of Reynolds Metals Extrusion Plant in Phoenix, Arizona. Mr. Miller's topic was "Industrial Development in Phoenix."

Mr. Walter Biddle of Biddle and Young Consultants addressed the Chapter in September on "Professional Registration."

The Chapter members heard a talk on Quality Control by Mr. Art Redlinger, of Sandia Corp., at the October meeting.

Mr. Jack F. Jericho, of United Airlines, who is the Western Regional Vice President of AIIE, was the principal speaker at the November meeting. His topic: "Changing Times In Industrial Engineering."

In December, Professor Al King, of the Arizona State University Industrial Engineering Department, spoke to the Chapter on "Organization of Industrial Engineering Departments."

CHATTANOOGA CHAPTER

The December meeting of the Chapter was a very interesting tour of the Davenport Hosiery Mill. Host for the evening was Lester Young, a member of the Chapter and Industrial Engineer for Davenport. Prior to the tour, Mr. Young covered the group on his company's products and incentive plan.

An occurrence of great interest to chapter members was the one-day conference held on February 13, 1959, and sponsored jointly by the Chattanooga Chapter and the University of Chattanooga. The subject was "Reduce Costs Through Work Measurement Techniques." The different Industrial Engineering subjects studied included: Advanced work measurement with Professor Cecil Johnson of Georgia Tech., and Time Study with Phil Carroll, Jr. of Carroll, Russell & Co., Rome, Georgia. Predetermined Time Study was led by Prof. Dan C. Doulet of the University of Tennessee. Work Sampling Study featured Prof. Harold Davidson, of Georgia Tech, and Richard P. Heller, of the duPont Dacron Plant at Kinston, North Carolina. Methods Study was under the direction of William Dykes, Consultant in Atlanta, Georgia.

Chapter members are looking forward with anticipation to the joint April meeting with the Middle Tennessee Chapter of Tullahoma. The program has been developed by them, and members of both Chapters will meet in Sewanee, Tennessee.

This is the first joint meeting of the two Chapters; however, officers of both Chapters have visited at Chapter meetings.

COLUMBUS, OHIO, CHAPTER

The first meeting of the 1958-59 business year was held in the Patio Room of the Pick-Fort Hayes Hotel on September 23. Dr. Gerald Nadler, Head of the Department of Industrial Engineering, Washington University, St. Louis, Missouri, addressed the group on "Industrial Engineering Techniques That Develop Manpower and Effectiveness." Dr. Nadler stressed more extensive use of Industrial Engineering Techniques such as simple charts and graphs, which showed measure of individual progress or progress of the unit, in production departments. The use of these should result in an increased effort from the workers to maintain or increase effectiveness.

Our October meeting was held on the 28th in the Conference Room of The International Business Machine Company. Mr. W. R. Mellin, Superintendent of Work Analysis, United Air Lines, presented a stimulating discussion of "Industrial Engineering and Operation Research." Mr. Mellin spoke of the Industrial Engineers activities and responsibilities in an Operation Research Group. He presented examples, pertaining to his own company, of the outstanding results which can be obtained from a well planned and organized Operation Research group and activity.

Mr. Henry W. Kelly passed away at his home on October 1. Mr. Kelly was a charter member of Columbus Chapter #1 AIIE. He was retired president of the Oran Company, a certified public accountant and a member of the Ohio Society of Professional Engineers.

LONG ISLAND CHAPTER

A September charter presentation dinner, attended by the wives, started the Long Island Chapter off on its first active year of operation. The dinner was a complete success with 90 attending, including representatives of the major industrial and educational institutions on Long Island. David Rosen, President of Manhattan Assembly Corporation, was the main speaker presenting an amusing tongue in cheek discussion of "Exhausto Dynamics." The new Chapter officers under the leadership of the first President, Herb Wendt of Long Island Lighting, were installed into office by Harvey Brock, Vice President of the Metropolitan Chapter.

The first regular Chapter meeting in October was an address, "The Industrial Engineer and Profits," by Mr. Alan J. Levy, Industrial Engineering Manager of Columbian Bronze Corporation. Mr. Levy reviewed the conceptual ideas underlying profits and highlighted by example the different calculations, assumptions and perspectives used in developing profits.

The November meeting was an address, "Computers and Operations Research," by Prof. Alan Steinberg, of New York University. Prof. Steinberg reviewed the logic behind the design of major data processing machines and the mathematics on how they work.

The regular monthly meetings have turnouts of some 40 men per meeting. The December meeting featured Mr. Harry H. Rains, Labor Relations Consultant, who spoke on "Human and Labor Relations for the Engineer." The Chapter now has seven active committees and intends to fulfill its plans of insuring active participation of the Industrial Engineering community of Long Island in AIIE work.

MEMPHIS CHAPTER

On November 19, our chapter met at the Union Planters Bank to hear Mr. Frank Buese of A. T. Kearney Company, Chicago, speak on M.T.M. Mr. Buese's talk included: What is M.T.M.? What are the Benefits? The origin of the Data for M.T.M.; An M.T.M. analysis of Movements; Applications of M.T.M.; and Development of M.T.M. as an additional tool to Industrial Engineering.

Our December meeting featured our own former chapter president, Joe B. Maloy, as speaker. His topic was "Linear Programming," with examples of practical applications. Mr. Maloy is a licensed Industrial Engineer with extensive practical, as well as teaching, experience.

METROPOLITAN NEW JERSEY CHAPTER

We were honored to have as guest speaker at our December meeting Mr. Floyd J. Titler, National Executive Secretary of AIIE. His topic was "The National Organization—AIIE." His talk to us outlined the structure and functions of AIIE, and covered the biographical expanse of the national organization as well as the chapter groups. He described the internal functions and interrelations of the executive committee, the Board of Trustees, the National Convention, and the committee chairmen. The many advantages and attractive features of membership in AIIE also were discussed and summarized.

On December 17, our chapter presented a full day conference on "Engineered Cost Control." This conference was held at the Suburban Golf Club in Union, New Jersey. The informal lectures and discussions covered the following subjects: Outline of Cost Control; Cost Control System Interrelations; Standard Cost Account Flow; Engineering Techniques for Determining Standard Costs; and Work Sampling Simulator—a group participation demonstration of a new technique.

MIDDLE TENNESSEE CHAPTER

David G. Dall, Southeast Regional Vice President of AIIE, was speaker at our regular November meeting which was held at Officer's Open Mess, Arnold Engineering Development Center. Mr. Dall, a group supervisor in the methods and planning section of the duPont nylon plant at Chattanooga, spoke on the national headquarters activity of AIIE.

Another feature of the evening was the continuation of the Management Business Game started by chapter members at the October meeting.

ST. LOUIS CHAPTER

At our December meeting, which was held on December 10 at "The Game Room" of the Carpenters' District Council Building, we had an especially interesting and entertaining program. It was the special presentation of "A Psychodrama" in three acts, seven scenes, produced and directed by Charles Wicks. The plot was based on an actual case, and took the form of a mystery. Different characters included: "Works Manager"; "Plant Superintendent"; "Chief I.E."; "International Union Representative"; "Union President," and several others.

Our January meeting featured Neil L. Barham of Perceptual Development Laboratories in St. Louis as the speaker. Mr. Barham's subject was "Industrial Engineering Uses for the Multifunction Perceptoscope." He has the position of Manager of Program Development and has devoted over five years of intensive and exhilarating research to this new technical field of Industrial Engineering and Education.

STUDENT CHAPTER CONFERENCE, SYRACUSE UNIVERSITY

The idea for this Student Chapter Conference, held on November 1, 1958, at Syracuse University, was initiated by Professor Charles W. Brennan, Director of Student Chapters, to encourage student participation at the Northeast Regional Conference which was also held in Syracuse. This was the first attempt to be made on a national level at sponsoring participation of students at any regional meeting.

The immediate purpose of the meeting was to bring together all possible student chapters in the Northeast Region so that informal, round table discussions could be held. Chapters sending representatives were: Lehigh University, Bethlehem, Pennsylvania; Northeastern University, Boston, Massachusetts; and Syracuse University. Some of the main points which were discussed were: interchange of programming ideas; how to improve affiliation between student and senior chapters; how to spark interest of underclassmen enrolled in the Industrial Engineering curriculum; and methods of improving and enlarging the scope of student chapters.

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WHAT IT IS

The I.E. Opportunities service is a functional committee activity of the AIIE. Information concerning employment opportunities is collected on a nationwide basis and is provided without charge to members upon request. The committee is composed of members from the Columbus, Ohio chapter.

SERVICES PROVIDED

Current job openings are published in condensed form in each issue.

In addition, a monthly I. E. Opportunities Bulletin is supplied to over seventy chapters located throughout the United States.

Each job opening is assigned a **"P"** number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

EMPLOYERS

Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

Industrial Engineers are often employed in such fields as Work Measurement, Production Control, Plant Engineering, Operations Research, Industrial Relations, Sales, and Management. For a more complete coverage, see the following list of job classifications. Please do not hesitate to forward information on jobs in any area where it is recognized that an Industrial Engineering background will be of value.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

This information will be publicized to the members in condensed form in the JOURNAL and in monthly chapter Bulletins. Company names are not shown.

MEMBERS SEEKING JOB OPPORTUNITIES

The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the **"P"** numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

ADDRESS OF THE SERVICE

I. E. OPPORTUNITIES SERVICE
American Institute of Industrial Engineers
145 North High Street
Columbus 15, Ohio

INDUSTRIAL ENGINEERING OPPORTUNITIES

Position number	Industry, location		Travel?	Job-classification number (See key)	Salary	Qualifications required			
					Range in $1,000	Adv. degree req.?	Years of exper.	Age range	
								from	to
17	Air Force	O		11, 13, 42, 31, 38	8.8		4–5		
41	Consulting	O	×	10, 21, 31			5–7		
167	Weapons Systems	Wash DC		50	Ph.D.				
177	Education	NY		50+Gen. I.E.		M.S. or Ph.D.			45
199	Govt. Agency	Panama		Engr. Trainee	5.6–6.7			20	
213	Aircraft Repair & Mod.	Cal		15, 32, 42, 43, 44, 53	7.5		2½	21	
257	Chem. Proc.	Pa, WVa, Va		10, 21, 43	Open		1–5	Open	
273	Air Force	Utah		10 through 19	6.3–7.5		1½–2½		
274	Maint. Control	SC		11, 18, 52, 71, 90	7.5–8.2		2½		
275	Maint. Control	SC		11, 18, 52, 71	4.4–4.9		0		
279	Airline	Ill, Colo, Cal		11, 13, 42, 43, 70	5.0–8.0		2–8		
281	Education	Mo		10, 31					
299	Education	Mass		10, 20, 30, 40, 50		M.S. or Ph.D.			
301	M. Consulting	Upper Midwest	×	Broad	10.0–14.0		5–	28	50
302	Missile Production	Wash		10, 30, 40, 50, 70	6.0–11.5		1–		
303	Air Force Depot	NY		13, 31, 40, 91	4.4–7.5		0–3		
308	Automotive	Pa		19, 36, 38, 53	6.6–9.6		4–6		
311	Aircraft	Cal		11, 13, 15, 18, 33, 34, 35, 42, 43, 44, 47, 54, 71, 91, 92			5–		
313	Aircraft	O		42, 43, 44, 34, 18	5.4–7.2		1–	24	42
314	Mfg.-Steel PrMd.	O		36, 39, 48, 80, 97			5–10	25	35
315	Air Force	Cal		10, 13, 15, 32, 38, 42, 43, 44, 53	5.4–7.5	1 yr Spec. Field	2½	21	
316	Mining	Nev		10, 20, 30, 40	6.0–9.5			21	45
317	Mgmt. Consulting	NJ		10, 20, 31, 42, 54, 70	8.0–12.0		5	30	45
318	Wood & Plastics	Va		10, 11, 14, 15, 16, 18, 22, 21, 23	8.0–10.0		3–5	28	38
321	Steel	Ontario		10, 11, 21, 38, 91, 26					
322	Steel	Ontario		10, 11, 38					
323	Steel	Ontario		50, 54					
324	Steel	Ontario		10, 11, 21, 42					
325	Steel	Ontario		38, 53, 49					
326	Steel	Ontario		10, 13, 14, 15, 21					
327	Education	Fla							

Position number	Industry, location		Travel?	Job classification number (See key)	Salary	Qualifications required			
					Range in $1,000	Adv. degree req.?	Years of exper.	Age range	
								from	to
328	Research & Edu.	Pa		26, 61, 64, 65					
329	Metal-Mach.	Mass		32, 36, 39	14.0–16.0				
330	Electro-Mech.	O		10, 16, 19	8.4–9.6		4–8	30	
331	Plumbing Goods	WVa		10	4.2–4.8				
332	Printing	NY		11, 13, 18, 36, 37, 42, 43			5		35
333	Edu. (Wood Prod.)	NY		30, 37, 40					
334	Education	Fla		10, 26, 31–36, 40–45, 53, 66					
336	Steel	Mich		38	8.0–10.0		2–5	25	35
337	Research & Devel.	NJ		11, 13, 42	6.2		2–3		
338	Steel	Mich		10, 11, 19, 36	–6.0			25	35
339	Automotive	Pa		11, 13, 15, 16, 22, 23, 36	6.6–9.6		4–6		
340	Automotive	Pa		13, 14, 15, 16, 22	5.4–7.8		0–2		
341	Printing	NY		10, 11, 22, 32, 42, 43	7.8–9.5		3–5		
342	Com. Refrig.	NJ		10, 13, 14, 15, 20, 21, 22	8.0–11.0		8–10	30	40
343	Com. Refrig.	NJ		31, 32, 33, 34, 35, 94	8.0–10.0		10–12	30	40
344	Hosiery	NC		10, 11, 30	4.0–6.0		2–5	25	45
345	Govt. Agency	Wash., DC		10, 11, 42	8.2				
346	Education	Ga		19, 53, 51 (Research)	7.0–10.0	Degree M.S. or Ph.D.	2–5	30	45
347	Electronic Prod.	Ind		16, 19, 36, 39					
348	Administrative	(East)		10, 11, 13, 67, 71	14.0–16.0				
349	Plastic Prod.	Va		10, 21	8.0	MTM		25	38
350	Plastic Prod.	Va		91	10.0	Aircraft Exp.		30	45
352	Air Force	O		50	5.7–12.5				
353	Chemical Plant	La		10, 72, 13, 38, 63 (91 in Chem. Plant or Refinery)	8.4–10.0		5–10	30	40
354	Oil Field Equip.	Tex		10, 30, 39, 40	7.2–7.8	Mach. Shop Exp.	2–5	28	38
355	Non-Ferrous Metals	New Eng		92	12.0–17.0	I.E. Deg. Pref.	10–15	35	45
356	Chem. Proc. & Min.	Canada		92	12.0–14.0	I.E. Deg. Pref.	10	30	40
357	Chem. Proc. & Min.	Canada		91	8.0–10.0		5–10	25	30
358	Paper Mill	Pa		10, 13, 15, 21, 42	6.0–7.2		3–		
359	Mining	Peru		10, 11, 13, 18, 36, 38	Open		5–		
360	Electronics	Mass		10, 26, 32, 34, 36, 38, 39, 42, 49, 70, 91	5.0–9.0	Exp. in Electronics	3–5		
361	Mfg. & Fabr.	Tex		10, 18, 32, 40, 70, 92	8.5–10.0	Exp. in Welding	5–10	30	45
362	Aircraft	Conn		50, 51, 52	Open	Milit. & Ind. Exp.	1–4		
363	Oil Field Equip.	Tex		10, 19, 30, 32, 39, 40, 47, 70, 92	10.0–	Mach. Shop Exp.	7–10	30	45
364	Mfg.	Tex		10, 19, 30, 38, 39, 54, 91	8.5–10.0		5–10	30	40
365	Metal Fabr.	Tenn		10, 11, 21	6.0–7.2			25	40
366	Graphic Arts	Ind		11, 13, 36, 42, 43, 70	5.8–7.0		0–3		
367	Paper	Mo		10, 20, 42, 43, 70					
368	Metal Stamping	Conn		36, 39, 42, 44, 47	10.0–15.0		10–15	35	50
369	Metal Stamping	Conn		94	14.0–16.0		12–18	35	50
370	Air Force	O			8.8–10.0		4½		
371	Textile Prod.	SC		10, 20, 30, 40, 50					
372	Education	Ala			8.0 plus 2.0	Sor Summer Term—Ph.D. Pref.			
373	Education	Fla		37, 42, 50, 51, 53, 54					
374	Govt.	S.A., Asia, Africa		41, 49, 92, 93, 95, 96	10.0–16.0		10–		
375	Electronics	NY		30–39, 70–73	7.5–9.5		5–10	32	45
376	Education	Mass						35	
377	Electronics	NY		10, 30, 40, 70	4.5–7.5				
378	Mgmt. Consulting	Ill	×	Broad	8.0–12.0		5–	28	40
379	Soft Goods Mfg.	Midwest		11, 13, 19, 31, 35, 43, 92, 93	12.0–		5–		45
380	Ind. Cons.	M.W. & S.W.		11, 13, 21, 31, 37, 42, 43	Open		5–		45
381	Steel	Ill		10, 20, 31–38	7.2–9.0	IBM Required	5–	27	35
382	Steel Proc. Warehouse	Mich		30, 40	Open		1–2		30
383	Govt. Agency	Africa, S.A., Near East, Far East		60, 70, 71	11.6–15.8	Management Exp.	10–		
384	Same as P-383			Broad	11.6–13.6				
385	Carpet Mfg.	South		10–19, 36	Open	I.E. Deg.	3–5		
386	Hospital	Ala		10, 30, 42, 53, 71, 72, 92	6.5–8.0	I.E. Deg. Reqd.	3–5	Open	
387	Electronic	Tex		80, 81	7.2–8.4		3–5		
388	Electronic	Tex		36, 38	7.2–8.5	Accounting Deg.	2–5		
389	Electronic	Tex		10, 11, 13	7.0–8.4	I.E. Deg.			
390	Electronic	Tex		36, 38, 70	7.2–9.6	I.E. Deg.	2–5	25	40
391	Electronic	Tex		30, 31, 32, 33	7.0–9.0			25	35
392	Power Shovels	Wisc, Ind, Pa		10, 11, 13, 14, 15, 16, 21					

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement
12	Suggestion Systems
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic
16	Predeter. Elemental Time Stds
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

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Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.